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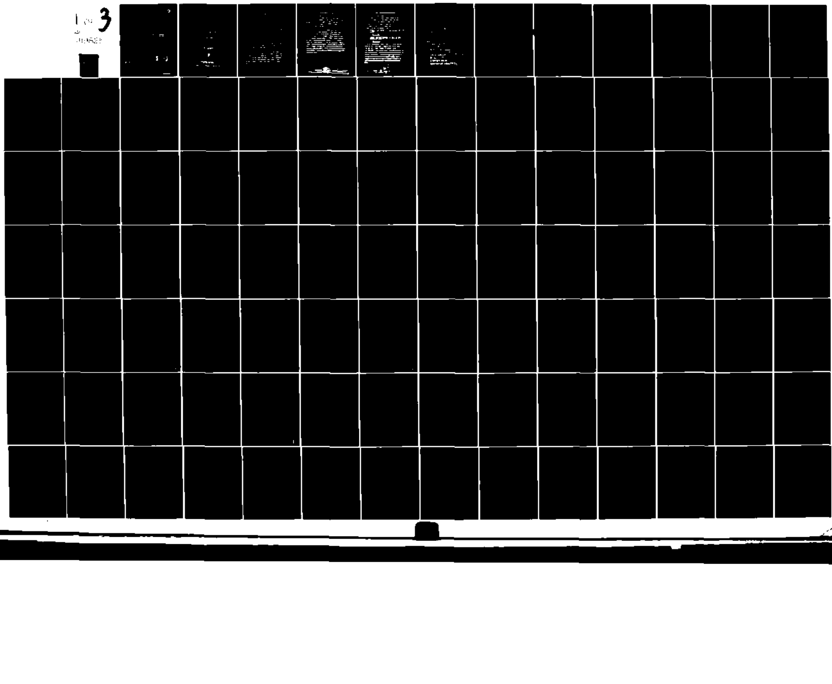

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FINAL REPORT

RTI/2265/00-04F

STATE-OF-THE-ART ASSESSMENT — SHELTER HABITABILITY

Prepared for:
Federal Emergency Management Agency
Washington, D.C. 20472

Approved for Public Release; Distribution Unlimited

RTI
Research Triangle Institute P.O. Box 12194 Research Triangle Park, North Carolina 27709

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Civil defense plans include two options for protecting the civilian population in the event of a nuclear attack on the United States. One would provide shelter for the population near their place of employment or residence while the other would relocate the population of likely target areas to areas of lower risk and would provide shelter in the host areas. Both options rely on the use of shelters to protect the population from nuclear weapons effects. The success of both options depends on the ability of people to be housed in shelters for an extended period of time and emerge with sufficient health and energy to implement recovery operations. To achieve success, the habitability performance of the shelters and [illegible] for the occupants.

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September 1982

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M. Wright
R. Chessin
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The objectives of this study were to assess the state-of-the-art of shelter habitability research, to describe nuclear weapons effects and mitigation techniques, to summarize current civil defense programs and policies, and to identify future research needs related to shelter

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The information obtained was summarized into a state-of-the-art assessment of research related to shelter habitability. General conclusions were listed to identify areas where there is general agreement among researchers. Recommendations for further study were made for areas where there is disagreement among researchers and where there are important unanswered questions.

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ABSTRACT

The objectives of this study were to assess the state-of-the-art of shelter habitability research, to describe nuclear weapons effects and mitigation techniques, to summarize current civil defense programs and policies, and to identify future research needs related to shelter habitability. The work consisted of an extensive review of civil defense literature, a review of noncivil defense literature through computer searches, and personal communications with individual researchers.

The information obtained was summarized into a state-of-the art assessment of research related to shelter habitability. General conclusions were listed to identify areas where there is general agreement among researchers. Recommendations for further study were made for areas where there is disagreement among researches and where there are important unanswered questions.

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I. BACKGROUND

A. Introduction

In recent years, civil defense planners have emphasized two major alternatives for protecting the civilian population in the event of a nuclear attack on the United States. The first alternative would be implemented should an attack occur suddenly, without warning, and consists of sheltering the population in the immediate vicinity of their locale at the time of attack. The second alternative would be implemented during a period of international tensions that could lead to war and consists of relocating (evacuating) populations of likely target areas into areas of lower risk where shelter from fallout would be provided. The success of both alternatives depends on the ability of people to be housed in a shelter for an extended time and to emerge with sufficient health and energy to implement a recovery from the attack. Success, then, requires that the internal environment of shelters be maintained at conditions not seriously or irreversibly detrimental to occupants.

Shelters may be considered in three classes: (1) general, or personnel, shelters, usually existing buildings brought into service as shelters during a crisis; (2) special, or working, shelters such as emergency operating centers; and (3) single-purpose shelters erected specifically to provide shelter during an emergency. The latter two classes are constructed and equipped for specific shelter purposes. They are therefore more likely to have environmental control systems designed into them than is the first class, which normally depends either on existing environmental control systems designed for other purposes or on expediently installed environmental control systems.

For many years, civil defense researchers have sponsored and conducted studies to identify problems associated with shelter habitability and to define techniques for maintaining a habitable shelter environment. These studies have consisted of analytical and experimental projects, as well as equipment design and development. The results of these studies have been used as the basis to establish minimum standards for the internal shelter environment and to develop guidance for installing expedient environmental control systems in shelters.

No recent studies have attempted to assemble the results of shelter habitability research into a state-of-the-art assessment. As with most other areas of study, such an assessment is needed periodically to aid planners in identifying additional research and development needs. The objectives of the research described herein have been to conduct a state-of-the-art study of shelter habitability and to identify remaining research necessary for adequate assurance that shelter plans are workable.

The remainder of this chapter briefly summarizes nuclear weapons effects, mitigation techniques, and current civil defense policies and programs. Subsequent chapters describe the important elements that determine shelter habitability, present the state-of-the-art assessment, and make recommendations for further study.

B. Summary of Nuclear Weapons Effects and Mitigation Techniques

1. Nuclear Weapons Effects

Nuclear weapons explosions differ from conventional weapon explosions in two very significant ways. First, nuclear explosions can be many times more powerful than explosions of the largest conventional weapons, and, second, the energy release from nuclear weapons differs from conventional weapon energy release. While almost all of the energy release from a conventional weapon is in the form of blast and shock, the energy release from a nuclear weapon is in the form of thermal energy, blast and shock, and nuclear radiation. The proportion of the energy released in each form depends on the weapon yield, height of burst, and other factors. A typical energy distribution from a fission weapon detonated in the air below 40,000 feet is 35 percent thermal radiation, 50 percent blast and shock, and 15 percent nuclear radiation.

Nuclear radiation energy is usually considered as having two separate components, initial nuclear radiation and delayed (or residual) radiation, often referred to as fallout. The initial nuclear radiation is that emitted from the fireball and the radioactive cloud within the first minute after a nuclear explosion. It consists of neutrons and gamma rays given off almost instantaneously and the gamma rays emitted by fission products and other radioactive materials from the weapon. Fallout radiation comes from radioactive solid and liquid particles that fall to earth from a nuclear weapon's cloud. These particles form when materials vaporized by the intense heat of a nuclear explosion condense to form particles that contain or are attached to fission products or other radioactive materials.

Fallout radiation consists almost entirely of gamma rays. The amount of energy released as fallout radiation depends on the height at which a weapon is detonated and the weapon design. If a fission weapon is detonated at a height such that the fireball does not touch the ground, fallout intensity is much lower than for weapons detonated at or near the earth's surface. Similarly, fallout from a fusion (thermonuclear) weapon is generally much less than that from a fission weapon because of the smaller quantity of fission fragments produced.

Thermal radiation from a nuclear weapon can produce severe burns on exposed individuals and may cause eye damage at great distances from the explosion. Thermal radiation is also capable of igniting fires in combustible materials at substantial distances from the explosion. These fires could produce additional personnel casualties. The distances over which thermal radiation is a threat depends on weapon yield, height of burst, atmospheric conditions, and the presence of intervening obstacles.

Blast effects consist of both air blast and ground shock. The air blast is composed of an overpressure and blast winds that accompany the shock front as it moves away from the detonation. Both effects decrease in intensity with distance from the blast center. Blast effects produce injuries both directly and indirectly. Direct injuries result from exposure of the body to the high pressure associated with a blast wave. Indirect injuries result from the impact of missiles on the body or from displacement of the body as a whole by the blast winds.

Nuclear radiation consists of high-energy neutrons and gamma rays that emanate from a nuclear explosion. Radiation injuries result when the radiation penetrates the body and damages or destroys body cells. The severity of the injury is a function of the total radiation dose received by the body and the length of time over which the dose is received [1].

2. Mitigation Techniques*

Mitigating the effects of nuclear weapons is best achieved by the use of a personnel shelter. Any solid, opaque material, such as a wall, hill, or tree, can protect individuals from direct injury by thermal radiation if the material is between the individual and the fireball. Inside a shelter,

*Most of this discussion is based on information in Reference 1. Other references are cited as appropriate.

protection could be obtained by avoiding exterior wall openings through which thermal radiation may enter the shelter. To prevent fires from being started in the shelter, exterior wall apertures should be covered by an opaque, noncombustible material.

Protection from combustion products that emanate from any fires ignited near a shelter by thermal radiation may be more difficult to achieve than protection from initial thermal radiation. One of the more effective countermeasures is to create a positive pressure inside the shelter by mechanical ventilation. Otherwise, a sealed barrier may be required [2,3]. Use of a positive pressure requires a source of uncontaminated ventilating air and, if such a souce is available, would not adversely affect shelter habitability. Use of a sealed barrier could interfere with shelter ventilation if barriers are needed on all shelter exterior surfaces.

Two actions that can be taken to reduce the possibility of injury from blast effects of nuclear weapons include structural strengthening of the shelter and prevention of air blast entry into the shelter. Structural strengthening reduces the susceptability of a shelter to structural failure and thereby reduces the likelihood of injuries caused by such failures. Prevention of air blast entry into the shelter can reduce injuries caused by whole body translation and by missiles, as well as direct injuries from the overpressure. Strengthening of a shelter structure can be achieved by adding intermediate supports to reduce span lengths and by otherwise strengthening structural members. These actions should not have a significant adverse impact on shelter habitability.

Prevention of air blast entry is accomplished by closing shelter exterior openings with blast-resistant coverings. Such closures will prohibit adequate shelter ventilation if permanent closures are used. The situation can be alleviated by protecting ventilation openings with blast closure valves.

Providing protection from the nuclear radiation that nuclear weapons produce requires that shielding material be positioned between the radiation source and the individuals to be protected. If protection is to be provided against initial nuclear radiation, the shield must be effective against both gamma rays and neutrons. Protection from fallout radiation requires only that the shield be effective against gamma rays. Gamma-shield effectiveness is a function only of the mass of the shielding material. Neutron shielding is more complicated because neutrons must first be slowed by an element with high atomic mass and then captured by elements with low atomic mass. Gamma rays are created in the slowing process, and a gamma shield must thus be included. Concrete and damp earth are good compromise materials for both neutrons and gamma rays. Shielding effectiveness can be improved by adding boron or iron to concrete. Expedient radiation protection is often provided by placing earth against exterior walls and roofs of shelter structures. Any actions that cover exterior openings into shelters can adversely affect the ability to ventilate the shelter. Therefore, to prevent such detrimental effects, special shielding procedures must be employed.

C. Civil Defense Programs and Policies

1. History

Modern civil defense in the United States had its beginning during World War I when the Secretary of War, as chairman of the National Defense Council (NDC), was made responsible for civil defense. Councils were established at State and local levels to handle matters such as morale, conservation of food and other resources, public health, and "Americanization" of aliens during the war years. In 1939, the NDC and local councils were reestablished. An Advisory Committee to the Council was established and, prior to Japan's attack on Pearl Harbor, was renamed the Office of Civilian Defense (OCD). OCD organized groups of volunteers willing to participate in activities such as the restoration of public services, fire fighting, public health, and communications. OCD was abolished prior to the end of World War II.

In 1948, an Office of Civil Defense Planning was created by the Secretary of Defense. In March 1949, President Truman transferred civil defense responsibilities to the National Security Resources Board. Following the outbreak of the Korean War, a Federal Civil Defense Administration (FCDA) was set up by executive order on December 1, 1950. FCDA received its statutory basis with the enactment of the Federal Civil Defense Act of 1950. Under the terms of this act, FCDA was given an important, though limited, role to operate an alert system, prepare civil defense plans for other Federal agencies, aid State agencies in preparing plans, provide training, disseminate civil defense information to the public, and provide financial support to States and cities in acquiring supplies and equipment [4].

From 1951 to 1958, FCDA initiated a number of programs. All States and territories passed civil defense acts, an attack warning system was developed, stockpiling of medical and other civil defense equipment was initiated, civil defense exercises were conducted by States and cities, civil defense training was provided, research programs were begun, and a system of emergency broadcasting was developed [4]. Despite these accomplishments, no real measures were instituted that provided for protecting the population from a nuclear attack. During the early and mid 1950s, the population would be instructed either (1) to evacuate the target area within a few hours or (2) to seek immediate, nearby cover. Such measures were in response to the likelihood that a nuclear attack would be by manned bombers.

With the advent of intercontinental ballistic missiles (ICBMs), warning times were reduced, precluding evacuation of cities. In-place fallout protection was viewed as the best approach for protecting the population against the effects of fallout from a distant explosion. In 1961, the Office of Civil Defense (OCD) was constituted to carry out civil defense responsibilities, including the development and execution of a fallout shelter program. The National Fallout Shelter Survey program was started in the early 1960s and included the survey, identification, and stocking of existing shelters. Initial survey efforts concentrated on large public fallout shelters (occupancy for greater than 50 persons) rather than on individual or family shelters. Later, efforts included surveying home basements for their shelter potential and identifying structures that could be upgraded to provide fallout protection. Current fallout shelter program activities include research aimed at improving the characterization of the nuclear hazard and its effects, development of standards and design concepts for fallout shelters, training and education of design professionals so they may more effectively incorporate fallout protection in buildings, educating the general public regarding radiation hazards and protection concepts so they may be better prepared to respond effectively during and after nuclear attack, and assistance to local governmental units in preparedness planning and response activities [5].

In the mid-1970s, the Defense Civil Preparedness Agency (DCPA), formerly OCD, began investigating the feasibility of evacuating populations in areas likely to be targeted in an attack (i.e., risk areas) into areas having lower risks (host areas). In 1978, the Department of Defense decided to implement an enhanced civil defense program with the emphasis on crisis evacuation. Such an evacuation, referred to as crisis relocation, would augment the existing shelter program and would be initiated during a period of mounting international tension when it appeared that a nuclear attack was imminent. Risk-area populations would be evacuated over a period of several days to host areas, where fallout protection would be provided. Essential risk-area activities, e.g., fire and police services and critical industries, would continue during the relocation period with blast protection provided in the risk area for those persons involved in essential activities. Persons involved in essential activities would commute in and out of the risk area on a daily basis.

In an attempt to improve federal emergency management and assistance, five agencies, including DCPA, were consolidated into one--the Federal Emergency Management Agency (FEMA)--in 1979. In addition to DCPA, the Federal Insurance Administration, the U.S. Fire Administration, the Federal Disaster Assistance Administration, and the Federal Preparedness Agency were combined under FEMA.

2. Current Programs and Policies

Beginning under DCPA and continuing under FEMA, civil defense has embraced two "Nuclear Civil Protection" options: in-place protection and crisis relocation. In-place protection, i.e., the best protection available (e.g., basements) at or near homes, schools, or places of work, would be implemented if a nuclear attack were initiated unexpectedly. Crisis relocation, i.e., evacuating high-risk populations to low-risk areas with fallout protection provided in the host area, would be implemented during a period of increasing international tension that could result in war. Both options consist of providing fallout shelter to people for an extended period.

Under the in-place shelter option, the risk-area population would require shelter against all nuclear weapons effects. Under the crisis relocation option, all-effects protection would be needed only by those critical workers who would remain in risk areas after evacuation; only fallout protection would be needed for the relocated population and for residents of areas outside the range of direct weapons effects.

To support the two nuclear civil protection options, federal civil defense agencies have identified all areas in the United States considered risk areas and have identified host areas to which the residents of each risk area could be relocated. Surveys have been and are being conducted in risk areas to identify the best available shelter against all weapons effects. Host areas are being surveyed to identify structures that could provide fallout protection either in their existing state or after expedient modifications to improve their protective capability. In addition, nuclear civil protection planners are developing detailed shelter use plans for each risk area and its associated host area. The objective of this program is to provide suitable protection for all of the population under each of the nuclear civil protection options.

Current civil defense programs related to shelter habitability involve developing estimates of equipment needs and formulating plans for storage and distribution of the resources needed to maintain a habitable environment in shelters. Resources considered in these studies are water containers, ventilation kits, commodes, and sanitation kits. Purchase and storage of these items are the eventual goal of the current programs.

A number of other programs are being pursued in support of the two nuclear civil protection options. Among them are development of adequate communication systems, development of transportation plans to relocate risk-area populations, development of food redistribution systems to support a relocated population, development of techniques to protect or relocate industries, and development of plans for providing emergency services such as police, fire, and medical help to a relocated population.

In addition, because the ability of people to emerge healthy from an extended shelter stay is of considerable importance to a successful shelter program, shelter environmental standards have been developed to assist civil defense planners in providing a shelter environment that will not be seriously or irreversibly detrimental to occupants [5].

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II. SHELTER HABITABILITY REVIEW

To develop reliable shelter use plans, civil defense planners must have an awareness of the environmental limits that individuals can endure without severe or permanent physiological or psychological damage, and they must have the resources to maintain shelter environments within those limits. Identification or development of the necessary environmental control resources further requires that techniques be available for predicting environmental conditions in shelters.

The following sections identify and discuss the elements that constitute the overall shelter environment, describe the parameters that must be considered in the study of each element, and present a summary of the research and development activities that have been devoted to predicting and controlling each environmental element.

A. Characterization of Shelter Habitability Elements

For the purposes of this study, shelter habitability is defined by the thermal environment, the chemical environment, the biological environment, and other considerations. Other considerations include conditions relating to shelter space, noise, and lighting. These latter aspects of shelter habitability are less critical to survival than the thermal, chemical, and biological environments and are, therefore, given much briefer treatments in the following discussion.

1. Thermal Environment

The thermal environment in a shelter is determined by the rate of heat and moisture (latent heat) exchange. If the rate of heat input is greater than the rate of removal, the thermal environment will become hot and humid and eventually approach an uninhabitable condition. If the rate of heat removal is greater than the rate of heat input, the shelter may become uncomfortably or unbearably cold. Heat input to a shelter may come from sources either outside or inside the shelter. Heat from outside the shelter includes solar heat, which may enter a shelter through exterior wall apertures, and combustion heat from fires that may exist adjacent to a shelter. This combustion heat can contribute to shelter heat by conduction through exterior shelter surfaces. Air that enters the shelter by natural or forced means may also contribute to the overall heat load in a shelter, although such heat will normally be in the form of latent heat because the outside air temperature will usually be lower than the air temperature inside an occupied shelter. Heat from inside shelters is produced by the shelter occupants, who generate metabolic heat having sensible and latent components, by any equipment that may be operating, and by activities such as cooking or water heating.

Prediction of the thermal environment in a shelter consists of estimating the rate of heat input and heat loss. Analytical techniques are available by which such estimates can be made if adequate data are available. Estimates of solar heat input require detailed climatic data and data describing the physical and thermal properties of shelter boundaries. Shelter boundary data are also needed to estimate the heat input from adjacent fires. Metabolic heat input depends on the metabolic rate and the activity levels of the shelter occupants. Heat input from equipment and activities that use a heat source can be estimated on the basis of energy use rate. Heat loss from a shelter can also be estimated if adequate data are available. Sensible heat can be lost from a shelter by conduction through shelter boundaries. Estimates of sensible heat loss require data that describe the initial conditions and thermal properties of the shelter atmosphere, the shelter boundaries, and the medium surrounding the shelter.

If the rates of shelter heat gain and loss can be estimated, equilibrium conditions of the thermal environment can be computed. Techniques for controlling the thermal environment in shelters can be developed on the basis of the results.

Controlling the thermal environment in shelters generally involves heat removal rather than heat input. Occupant stress due to high temperatures is much more likely than stress due to low temperatures. With adequate clothing, shelter occupants could, without severe stress, withstand most low-temperature situations that would be encountered.

Heat can be removed from a shelter by conduction through the shelter boundaries, by ventilation, or by mechanical means such as evaporative cooling or refrigeration. Heat removed by conduction through the shelter boundaries can be estimated analytically if the initial thermal conditions and the heat transfer characteristics of the shelter exterior structural elements and of the surrounding medium are known. Heat removed by ventilation is a function of the thermal conditions of the ventilating air, the manner in which the air moves through the shelter, and the degree of mixing that occurs in the shelter. Ventilation may occur from natural forces such as the wind or buoyancy caused by temperature differences, or it may be forced by mechanical means such as manual or electric fans, blowers, or air pumps. In each case the ability and rate of shelter ventilation depend on the existence or availability of openings in the shelter boundaries.

The rate of heat removal by either evaporative cooling or refrigeration is dependent on the capacity of the units and the conditions of the external environment. However, either technique requires a source of energy in addition to the equipment itself, and evaporative cooling would not be applicable in geographic locations where high ambient humidity is prevalent. Thus, the applicability of these devices depends on the availability of the equipment, the availability of an energy source, and the climatic conditions.

Latent heat may be removed from a shelter by ventilation or condensation. The rate of latent heat removal by ventilation depends on the parameters described above. Latent heat removal by condensation may occur naturally at the shelter boundaries or may be induced by refrigeration. Heat removal by condensation at the shelter boundaries can be estimated if the initial conditions and thermal properties of the shelter exterior elements and the surrounding medium are known. Latent heat removal by refrigeration is again dependent on the availability of the equipment and a source of energy.

2. Chemical Environment

The chemical environment in a shelter is dependent on a number of factors. For the chemical environment to remain habitable, there must be a sufficient supply of oxygen to support the respiratory requirements of the occupants, and the concentration of carbon dioxide and other toxic or hazardous gases must be kept sufficiently low to prevent serious or irreversible damage to the occupants. The concentration of oxygen and carbon dioxide in a shelter depends on the rate of oxygen depletion and carbon dioxide production and on the rate of air exchange with the outside atmosphere. These parameters can be estimated from the respiratory requirements of the shelter occupants and the shelter ventilation rate if the distribution of the ventilating air over the shelter is also known. Respiratory requirements depend on the physical character of the individual shelter occupants and the level of their activity. The rate of air exchange or ventilation depends on the availability of ventilation equipment and exterior openings in the shelter. Air distribution within a shelter depends on the internal configuration of the shelter and the availability of auxiliary air distribution equipment.

There are a number of extraneous sources that have the potential for degrading the chemical environment in a shelter. If any fuel-burning equipment or activities exist in a shelter, oxygen will be consumed, and carbon dioxide, carbon monoxide, and other combustion products may be released. There is also the potential for bringing combustion products into the shelter along with the ventilating air if there are fires nearby or adjacent to the shelter structure. All of these potential contaminants must be considered in assessing the chemical environment in a shelter. Control of these contaminants could require either a sealed shelter or that a positive pressure be maintained in the shelter.

3. Biological Environment

The biological environment is comprised of the following:

- Microscopic and near microscopic pathogens (organisms that cause infectious disease) and allergens (foreign substances that cause an allergic reaction)
- Vermin, including vectors and reservoirs of disease (e.g., body lice, fleas, rats), as well as animals of an objectionable nature only (e.g., head lice).

The biological environment, particularly pathogens and their vectors, is important to the study of shelter habitability primarily for its communicable disease potential. The other biological elements typically are not debilitating or life threatening but represent a nuisance that should be minimized.

Prior to occupancy, shelters will contain few or no pathogens. Pathogens may occur in shelters in connection with the presence of vermin and will be brought into shelters in and on the bodies of occupants.

Allergens--agents (e.g., pollen, mold, and mites) that can cause allergic reactions--are likely to exist in shelters prior to occupancy and represent a nuisance in most instances. Although allergic reactions may be debilitating for some highly sensitive people, they are not likely to have a significant impact on shelter habitability and will not be considered in the same detail as communicable diseases.

Vermin are harmful (e.g., disease transmitting) or objectionable animals, including insects, arachnids, rodents, and bats. They may be present in shelters prior to their occupancy (e.g., rats and bats) or may be brought in on the bodies of occupants (e.g., head lice).

Several important factors in predicting the extent to which microorganisms and vermin will be a problem during the shelter period include the following:

- The presence of pathogens in the population as it enters the shelter
- Characteristics of pathogens/diseases present in shelter occupants, e.g., incubation period and route of transmission
- The proportion of susceptible (non-immune) persons among the shelter population
- The provision of adequate sanitation measures for control of pathogens and vermin
- The other shelter elements, e.g., temperature and space.

Potentially important factors in controlling outbreaks of communicable diseases in shelters include the following:

- Sanitation measures to remove sources of infection and harborage for disease vectors
- Drug treatment to halt the disease's progress in symptomatic persons
- Immunization of nonimmunized persons before entering shelters to reduce transmission of infection
- Isolation of infected persons to control disease transmission.

4. Other Considerations

Shelter habitability elements such as light, noise, and space are integrally related to the comfort of shelter occupants, though they may not have the direct physiological connection to shelter habitability that thermal, chemical, and biological elements do. Occupant comfort is both psychological and physiological. Under shelter conditions the most critical needs are maintaining physiological balance.

Space must be sufficient to allow for minimal personal belongings, for private bathing and toilet facilities, for ventilation and lighting equipment (as necessary), and for movement by occupants. Space is also related to the thermal environment. Humans will contribute to the heat load, and, under warm conditions with minimal air exchange, heat generated by shelter occupants could aggravate the thermal environment. Crowded shelter conditions will more likely contribute to thermal stress.

The spatial needs of handicapped, young, pregnant, or other special individuals may place additional pressure on available space. However, space has not been considered a serious problem in past studies. Under adverse conditions people adapt to limited space relatively easily. Social customs are quickly altered to accommodate environmental stresses.

Noise in a shelter will consist mostly of human noises. Flat, reflective surfaces of the shelter can add to problems of noise. Again, noise is an easily controlled element through voluntary actions and simple modifications to shelter surfaces. Infants or, possibly, psychologically distressed individuals are the least controllable source of noise other than external noise.

Most shelter activities can be carried out with little or no light. Minimal lighting is highly desirable, however, and adequate lighting must be available if medical treatment is to be undertaken. A diurnal pattern of light is also highly desirable for individuals to maintain sleep and awake patterns. A healthy level of comfort can be maintained with light for such activities as reading, food preparation and distribution, and general hygiene.

Providing light in shelters may affect the thermal or chemical environment. Electrical lights may add substantial amounts of heat to the shelter environment, and, where flames provide light, both heat and combustion products are potentially hazardous. These factors must be considered when the lighting needs of the shelter are assessed. However, minimum lighting should not be a serious problem.

B. State-of-the-Art Assessment

1. Thermal Environment

Numerous past research studies are related to the thermal environment in shelters and have generally been aimed at one of the following three objectives: (1) predicting the thermal environment, (2) controlling the thermal environment, or (3) monitoring the thermal environment. The following discussion gives separate treatment to studies related to each of these objectives.

a. Thermal Environmental Prediction

Projects aimed at predicting the thermal environment include weather studies, analytical studies, heat load analyses, soil property studies, and experimental fire studies. In 1964, Baschiere and Company developed an analytical procedure to predict the ventilation requirements of fallout shelters ventilated with ambient air [1]. Historical weather data from several locations and metabolic data developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) were used with the analytical procedure to estimate ventilation requirements to maintain an effective temperature (ET) of 85° F or less. Heat loads from lighting and equipment as well as solar loading and/or heat loss through shelter boundaries were considered. The authors compared their predictions to experimental results in several shelters and found agreement within 2° F ET in the steady state. Based on the study, the authors concluded that, for the purpose of predicting ventilation requirements, shelter boundaries should be considered adiabatic.

In 1965, Drapeau and Baggette analytically investigated heat conduction from an underground shelter [2]. Six mathematical solutions using three models--one-dimensional, spherical, and cylindrical--were investigated. After comparing their predictions with experimental data, the authors concluded that the cylindrical model is most appropriate for small shelters, that the one-dimensional model is more suitable for large shelters, and that the spherical model is best used for deeper shelters. The authors further concluded that initial temperatures are important only during the first week of occupancy and that the thermal properties of the media surrounding the shelter space are important to heat conduction.

In 1966, Kusuda and Achenbach conducted heat transfer analyses for underground shelters by computer simulation using both one-dimensional and three-dimensional models [3]. After comparing predictions with experimental data, the authors concluded that, for large shelters, the one-dimensional model is adequate to predict the thermal environment and that, for small shelters, the three-dimensional model should be used.

In 1968, Rathman and Baschiere published a user's manual for a shelter environmental prediction (SHEP) computer code developed over the period 1963 to 1968 to calculate the environmental response of a shelter over time to varying thermal loads and psychrometric conditions of inlet air [4]. Information that must be input to the code includes the shelter's physical, thermal, and geometrical characteristics; occupancy levels and duration; and hourly conditions of inlet air. The code accounts for solar radiation, boundary surface heat transfer, moisture evaporation or condensation at the shelter boundaries, equipment and lighting levels, and air conditioning. Simplifying assumptions include complete instantaneous mixing of shelter and ventilation air, filmwise moisture condensation and evaporation, negligible radiative energy exchange between shelter boundaries, and nontemperature-dependent thermal and physical properties of the air and structural materials.

In 1967, Baschiere and Lokmanhekim predicted the ventilation requirements of shelters by geographic location throughout the United States [5]. Historical weather data from 91 weather stations and an adiabatic shelter model were used to predict the ventilation requirements. National maps were developed to show the ventilation requirements to maintain effective temperatures of 80°, 83°, 86°, and 90° F for adequacy levels of 80, 85, 90, 95, and 99 percent. Adequacy level represents the fraction of hours during a year that the desired effective temperature can be maintained. The authors proposed that 82° F adjusted ET and a 90 percent adequacy level be used as national design values.

In a later study, Rathman investigated the effects of extreme weather conditions on the shelter environment, investigated the effectiveness of Kearney pumps as a means of distributing air in multiroom shelters, and compared weather bureau station wind data with wind patterns over an urban area [6]. In this study, the author used an adiabatic shelter model to predict environmental conditions in shelters during extended periods of extreme cold and extreme heat. Based on the analyses, it was concluded that survivable conditions can be maintained in shelters ventilated at a rate of 3 cfm per occupant (the minimum for controlling the chemical environment), even during extended periods of extreme cold. Thus, shelter heating should not be a consideration in civil defense planning. It was also concluded that, based on historical weather data, ventilation rates of 3 to 4 times the recommended rates may be required to prevent effective temperatures greater than 82° F from occurring for periods exceeding 24 hours. This conclusion was based on an analysis of weather data from four cities.

In a subsequent part of the study, the usefulness of Kearny pumps to distribute air in multiroom shelters was experimentally evaluated. It was concluded that Kearny pumps are ideally suited to this application. In the final part of the study, wind data from a weather bureau station were compared with wind data from a nearby urban area over a 2-month period. The author concluded that the correlation between the data sets is sufficient to permit using weather bureau data to predict wind-induced ventilation in above-grade shelters.

Most of the shelter ventilation studies contain an implicit assumption that ventilating air is evenly distributed to shelter occupants so that the psychrometric conditions of exit air are equivalent to the environmental conditions throughout the shelter. In actual shelters, such a situation will seldom exist. Instead, the ventilating air will pass progressively past a number of shelter occupants and will be at different psychrometric conditions at different locations between inlet and exit. In 1970, Allen developed a nonisostate shelter model to investigate the ventilation requirements in shelters that do not have ventilating air evenly distributed to each shelter occupant [7]. He concluded that, in many situations, the recommended ventilation rates, which were developed using an isostate shelter model, are insufficient to maintain the desired environmental conditions. In the same study, the author concluded that, under cold weather conditions, partial recirculation of shelter ventilating air may be required to prevent occupants from being exposed to extreme cold.

In 1966, Humphreys, Henschel, and Lee developed equations to predict the sensible and latent heat losses from individuals as a function of total metabolic heat rate and environmental conditions [8]. Clothed and nude individuals were considered. The equations were developed for a standard person and give factors by which heat loss estimates for nonstandard persons can be made. This study was followed by a study by Pefley, Cull, and Sekins wherein experimental measurements of sensible and latent heat losses were made [9]. The experiments were conducted in a monoman calorimeter and included a wide range of subjects in varying states of dress and a wide range of inlet air conditions.

Weather station data are used to predict shelter ventilation requirements in the area around the station. Because many shelters are located in built-up (urban) areas, two studies were conducted by Ludwig to investigate the relationship between temperature data from the weather station and those from nearby urban areas [10,11]. Based on these studies, the author concluded that daytime temperatures in urban areas are 0.5° to 1.0° C higher than weather station temperatures and that urban nighttime temperatures are 9° C higher than those at the weather station.

In the late 1960s, Waterman undertook a series of experimental studies to investigate the effects of fire on the thermal and chemical environments in adjacent shelters [12,13]. Based on his studies, the author concluded that fire gases do not signficantly heat shelter air but that, if the fire is immediately adjacent to a shelter boundary, a significant hazard might exist because of heat transfer through the structural materials. It was further concluded that heat transfer through the ceiling from an overhead fire creates a greater hazard than heat transfer through a wall from an adjacent fire. The author found that the hazard can be reduced substantially by incorporating an air gap (for insulation) in the wall or ceiling adjacent to the fire.

Analytical procedures developed to calculate shelter heat transfer indicate that thermal properties of soil are important to the state of thermal equilibrium in underground shelters. The scarcity of soil thermal property data led to several research efforts to obtain these data. In one study, Kusuda and Achenbach developed a procedure for predicting earth temperatures to a depth of 10 feet using climatological data from 63 locations in the southern and western portions of the United States [14]. Temperatures predicted with the procedure agreed reasonably well with available earth temperature data. The procedures were therefore concluded to be adequate for use in analyzing heat transfer in underground structures. In two later studies, Kusuda developed instrumentation and collected earth temperature data over a 2-year period [15,16]. Data were collected at depths to 30 feet under five different surface conditions: paved, paved and painted, bare, short grass, and long grass. Based on the data collected, the author concluded that ground temperatures to a depth of 10 feet are considerably affected by the surface temperature and that the temperature of soil under paved surfaces are significantly higher than that of soils under the other surface types. It was recommended that, for underground shelter analyses, the earth temperature be increased by 15° F above current design values if the ground surface is paved.

b. <u>Thermal Environmental Control</u>

Studies aimed at controlling the thermal environment in shelters have mostly been concerned with removal of excess heat, although a few studies have considered the problems of cold temperatures. Major emphasis has been given to the use of ventilation, both naturally occurring and forced, as a means of disposing of excess heat, with less emphasis given to mechanical and chemical means. Ventilation studies have included equipment development, analytical procedures, actual and simulated shelter occupancy tests, and experimental programs using shelter models.

In 1962, Flanigan initiated an extensive series of shelter occupancy studies using simulated occupants [17]. The 24 shelters used in the study were widely distributed over the United States and all but one of the shelters were underground. The simulated occupants were designed to produce sensible and latent heat in the same ratio as real occupants and the ventilating air was conditioned to represent a typical summer day in the geographic location for each shelter. In each test, the ventilation rate needed to maintain ET's below 85° F was identified. The results of the tests were used to develop an analytical procedure for predicting the ventilation rate required to achieve a specified ET. The procedure was used to calculate the ventilation rate that would be needed in each of the tested shelters if the shelter walls were adiabatic. During each test, psychrometric conditions of inlet and exhaust air were monitored and soil temperature and moisture content were recorded. In some of these tests, heat removal by means other than ventilation was investigated. Techniques tested included the use of well water to cool the ventilating air, evaporative coolers, desiccants, and mechanical dehumidifiers. In one test, a fire was ignited above the shelter to measure its effect on the shelter thermal environment.

Based on the experimental results, the author concluded that the ventilation rate of 3 cfm per occupant required to maintain a chemical balance in shelters is not adequate for temperature control in most geographic locations during warm weather; that an overhead fire does not adversely affect the thermal shelter environment if there is a 3-foot earth cover, although the chemical shelter environment may be adversely affected; that well water and coils are effective in reducing shelter ET's; that evaporative coolers are effective in reducing shelter ET's, although they require more energy input than can be produced by the shelter occupants; that desiccants and mechanical dehumidifiers operated inside a shelter increase rather than decrease the ET; and that soil thermal conductivity is a strong function of soil moisture content.

Other simulated occupancy tests were conducted by Guy B. Panero, Inc., and by the MRD Division of General American Transportation Corporation [18,19]. Panero conducted tests in 8 shelters and concluded that above-ground shelters generally are adequately ventilated by natural means but that below-ground shelters need forced ventilation or a means of cooling the ventilating air. He further concluded that Kearny pumps, which are manually powered air pumps consisting of a series of overlapping flap valves, can improve the air distribution in shelters and prevent the stratification of air. The MRD tests were made in 10 shelters, both above and below ground, in various geographic locations. Conclusions from these studies were that above-ground shelters have adequate natural ventilation and that the shelter diurnal cycle closely follows the ambient cycle but at an amplitude of only 15 to 50 percent of the ambient. It was further concluded that, for predicting the ventilation requirements of below-grade shelters, no credit should be taken for heat loss through shelter boundaries unless detailed data are available describing soil thermal properties.

In a later ventilation test [20], Henninger and Madson found adequate natural ventilation from the wind in an upper story shelter in Chicago. An effectiveness factor for exterior wall apertures was experimentally determined.

Most of the researchers who investigated natural ventilation as a means of controlling a shelter thermal environment agreed that wind-induced ventilation is adequate for above-ground shelters. There was also general agreement that wind-induced ventilation is not adequate to control the thermal environment in below-ground shelters. A number of other studies were intitiated, using both actual and simulated shelters, to investigate thermally driven or gravity-induced natural ventilation as a means of environmental control in underground shelters. Thermally driven ventilation is gravity induced by the stack effect (buoyancy forces) that result when air inside a shelter is heated metabolically by the shelter occupants.

Pennsylvania State University undertook a series of studies to develop techniques for measuring natural draft in shelters and to measure the amount of gravity-induced ventilation in several shelters [21,22,23]. After completing the tests, the author concluded that gravity-induced ventilation is not sufficient to maintain a tolerable thermal environment during periods of hot humid weather. Other researchers undertook studies of gravity-induced ventilation as well. The National Bureau of Standards [24] used a scale model shelter and used hot, pressurized water as the working fluid to study the phenomenon. These experiments produced data that describe the way air moves in a shelter ventilated only by gravity-induced ventilation.

McCreery developed a Ventilation Analysis Procedure (VAP), which is a graphical method of predicting gravity-induced ventilation for shelters based on the physical characteristics of the shelter structure [25]. Following this, Wright conducted a series of experiments in a full size shelter model to measure gravity-induced ventilation for a number of floor plan and aperture configurations using heat loads to simulate various numbers of shelter occupants [26,27]. Burns also conducted a series of experiments to verify the VAP methodology [28]. The experiments by Wright indicated that the VAP methodology overestimates the magnitude of gravity-induced ventilation by about 20 percent.

In another study, Whitehill et al. investigated the use of induced draft as a means of ventilating family-sized underground shelters [29]. In this study, a kerosene lantern was mounted at the base of an air exhaust stack and served as a light source and as a heat source to induce airflow through the shelter. The author concluded that the technique was reliable for providing minimum (i.e., 3 cfm per occupant) ventilation to the type of shelter tested.

In a 1966 study by Stanford Research Institute (SRI) [30], results of completed ventilation research were evaluated and additional research needs proposed. A major conclusion reached was that air distribution in shelters is important to shelter habitability and that additional study of the problem was needed.

Research was in fact already underway to investigate air distribution problems. Taylor and Gonzalez conducted a study in a simulated 1,000-person shelter at Fort Belvoir, Virginia [31]. They discovered that the average thermal response of the shelter as a whole closely followed their predictions but that individual rooms not in the direct flow path of the ventilating air achieved ETs much higher than predicted. Auxilliary air distribution equipment (Kearny pumps) was required to alleviate the problem.

Svaeri and Stein also conducted air distribution studies at the Fort Belvoir facility [32] to study the effectiveness of Kearny pumps as air distribution devices. They concluded that Kearny pumps are capable of maintaining a habitable environment in side rooms outside the normal air flow path and that they are beneficial to occupant comfort in open areas of shelters by improving air circulation.

Rathman also investigated the use of Kearny pumps to improve shelter air distribution [33]. He concluded that single Kearny pumps can adequately distribute air into flow-through rooms with areas up to 800 square feet and in "very small" dead-end rooms. He further concluded that Kearny pumps help to provide adequate delivery and distribution of air when used in conjunction with fans to supply the ventilation air.

Subsequent studies by Research Triangle Institute (RTI) investigated air supply and distribution in large single-room and multiroom shelters [34,35]. Conclusions from these studies include verification that package ventilation kits (PVKs) are effective in supplying air to large shelters, that Kearny pumps are effective in distributing air up to about 50 feet outside the normal airflow path in a large open area, and that Kearny pumps can ventilate dead-end rooms up to 600 square feet in area.

A more recent study by RTI [36] investigated the feasibility of adding expedient openings in interior and exterior walls to promote better air distribution in shelters. In that study, methods of providing such openings were reviewed and the effects of the openings on air distribution were experimentally measured.

A recent study by General American Research Division (GARD) investigated the adequacy of wind ventilation in upgraded shelters such as would be prevalent in host areas during crisis relocation [37]. These tests were conducted using a scale model shelter and a low-speed wind tunnel. The authors concluded that, except for a few areas in the Southeastern United States, wind ventilation is adequate for these shelters.

During the time that ventilation studies were being made, other research and development activities concerned with ventilation equipment were also conducted. In 1965, RTI surveyed a statistical sample of shelter facilities identified as needing additional ventilation to maintain a habitable environment when fully occupied [38]. From this study, estimates of physical shelter characteristics were obtained. These estimates served as a basis for designing and deploying ventilators in shelters.

About the same time, GARD began a series of studies to develop portable ventilation equipment for use in fallout shelters. Plans and specifications for a portable fan that could be driven either manually or electrically were developed in one study [39]. This study was followed by two others to evaluate both the ventilator and its operators over an extended period of continuous manual use [40,41]. Several mechanical failures occured during the first study, which was continued over a 2-week period. The studies resulted in a conclusion that most shelter occupants would be able to operate the ventilator under any of several operating schedules.

Cresson Kearny developed an air moving device based on the principle of the punkah. The device consists of a series of overlapping flap valves attached to a rectangular frame hinged at the top. The device is referred to as a Kearny pump and was included in shelter ventilation studies performed by several researchers, some of which have already been mentioned. In an SRI study [42], Kearny pump performance curves were developed and the device was tested as a means of supplying air to dead-end rooms. The author concluded that a half-door-sized Kearny pump could supply 890 cubic feet of air per minute to a dead-end room. The tests also demonstrated the usefulness of the device as a means of mixing air in a shelter.

In later studies, GARD analyzed a sample of identified shelters to determine the most appropriate ventilation units from among 600 fans under consideration [43]. From this analysis, the authors were able to identify the best 3 units for further consideration. Performance characteristics and costs of these 3 units were studied in more detail in a separate project [44].

In another study by GARD, the geometrical characteristics of shelters were analyzed and related to the flow characteristics and capabilities of ventilation equipment [45]. From this study, the author concluded that only 6 percent of the shelters have insufficient exterior openings to permit the required ventilation to be delivered by manually powered fans. He also concluded that air is not properly distributed in the shelters when the fans are used alone and recommended that Kearny pumps be included in shelter ventilation systems to increase the occupiable portions of shelters.

GARD subsequently conducted tests to determine if shelter occupants are able to set up and use pedal powered fans and Kearny pumps [46]. After three test sessions, the investigators found that most activities were carried out properly and that equipment deployment was the most difficult task. Revisions to existing instructions were recommended. Minor design revisions and further durability tests of both pedal ventilators and Kearny pumps were accomplished in still another GARD study [47].

In a more recent study, GARD researchers reevaluated the design specifications of the pedal ventilator and Kearny pump to identify recent materials and/or manufacturing techniques that could be cost effectively incorporated into the devices [48]. Revised equipment specifications were developed as a result of that investigation.

Heat removal techniques, other than ventilation, were also investigated for potential applications in fallout shelters. In the shelter occupancy studies conducted by the University of Florida [17], several alternative heat removal techniques were considered, including pumping well water through coils, evaporative coolers, desiccants, and mechanical dehumidifiers. From these investigations, it was concluded that well water pumped through coils is an effective way to cool shelters if a water source is available, that evaporative coolers are also effective but require more than muscular power by shelter occupants, and that desiccants and mechanical dehumidifiers actually increase shelter effective temperature and thus are deterimental to the shelter thermal environment. In a study by Charanian et al., it was concluded that an ideal system of temperature-humidity control is the combined use of desiccants and well water if ventilation is not adequate or cannot be used (e.g., in a closed shelter situation) [49].

Several research studies were undertaken by Battelle Memorial Institute to investigate alternative heat removal techniques. In the first [50], a number of unconventional cooling systems were evaluated to identify the more promising candidates for shelter use. This was followed by detailed design and cost estimates for an air-cycle cooling system [51] and an open-cycle methanol system [52]. Both were found to be suitable for shelter cooling if a source of power is available. In the methanol system, there is the potential of using the spent methanol as fuel for an engine to drive the unit.

Southwest Research Institute evaluated a number of absorption-based cooling systems for potential applications in shelters [53]. The investigators in this study concluded that the most useful system for shelters is an aqueous ammonia system with direct heat rejection to ambient air. The system would be used to chill water, which would then be circulated through the shelter, and would use manual power to pump both water and air.

Carrier Air Conditioning Company designed and built a portable, 3-ton air conditioning unit for use in fallout shelters [54]. The unit used a standard freon compression-expansion cycle, was electrically powered, and would be located outside the shelter.

Several of the studies mentioned above indicated that well water could be used to cool shelters if water is available. As a follow-up to these indications, SRI conducted a study of the feasibility of providing well water for cooling [55]. Investigators evaluated several techniques for drilling wells within a shelter after occupancy. They concluded that sonic drilling methods are the most suitable for the purpose but also determined that operating wells could not be developed in time to prevent excessive temperatures from occurring.

GARD conducted several studies concerned with the use of evaporative coolers for shelters. In one study, the adequacy of natural ventilation with evaporative coolers was evaluated [57]. Ten-year weather data were used to predict the adequacy of wind-induced ventilation at 19 weather stations. It was determined that evaporative coolers are capable of maintaining ETs within habitable limits in all areas of the country but that forced ventilation would also be required. In a third study [58], GARD researchers determined that evaporative coolers can reduce ventilation requirements by 5 to 40 percent.

Further study of the use of standard air conditioning units in shelters was carried out by Pennsylvania State University [59]. Several designs of existing air conditioning units were evaluated to determine their adaptability to shelter cooling. Several units were found to be suitable with minimal modifications, but their use would depend on a source of electric power.

Under contract with the National Science Foundation, Kansas State University investigated the use of dry ice as a means of personal cooling

[60]. The technique was determined to be a feasible means of personal cooling in hot environments, but the suitability of the technique in a shelter environment would probably be hampered by the unavailability of dry ice and could cause excessive concentrations of CO_2 if ventilation is restricted.

Although a number of cooling techniques were investigated, ventilation with ambient air continues to be favored as the means of controlling shelter thermal environments. In 1970, Wright developed a procedure to estimate the ventilation equipment needs for individual shelters and provided instructions for positioning the equipment in shelters of various configurations [61]. The study was later updated by York to consider a single ventilator size and to take into account recent research results related to ventilation deployment [62]. In the latter study, alternatives for the storage and distribution of ventilator stocks were also investigated and a recommended system developed.

RTI conducted several other studies related to controlling the thermal environment in shelters. In one study, a ventilation system powered by portable engine generators was installed in an underground mine to demonstrate the feasibility of providing such systems on an expedient basis [63]. This study was followed by development of a local civil defense planners manual describing procedures that could be used to install expedient ventilation systems in mines [64]. In two other studies, RTI researchers developed procedures for connecting engine-generator sets into the electrical distribution systems of large and small shelter structures [65,66]. This procedure would allow the use of existing lighting and ventilation systems when the normal source of electric power is unavailable.

c. Thermal Environmental Monitoring

Only a few civil-defense-sponsored studies have been concerned with shelter environmental monitoring. Thomas A. Edison Research Laboratory developed a recommended environmental instrument package for shelters [67]. In that study, the recommended instruments for monitoring the thermal environment were a liquid in glass or differential expansion thermometer for temperature and a sling psychrometer or animal membrane hygrometer for humidity. It was also recommended that an instrument be developed to directly measure ET.

In a later study, GARD developed three direct-reading ET meters and then performed evaluations of those three and two others that had been developed by others [68]. The most promising of the meters tested was identified and recommended for further development.

2. Chemical Environment

As was the case with the thermal environment, most studies related to the chemical shelter environment were aimed at predicting, controlling, or monitoring the chemical environment. The effort devoted to studying the chemical environment is much less than that devoted to studying the thermal environment.

The most obvious potential hazard in the shelter chemical environment is the depletion of oxygen and a corresponding build up of carbon dioxide (CO_2) that results from respiratory functions of the shelter occupants. A number of research studies have indicated that prolonged exposure to CO_2 concentrations above 0.5 percent can lead to lasting physiological damage [67]. A level of 0.5 percent was therefore adopted as the upper limit of CO_2 concentration in shelters [69]. Calculations by ASHRAE [70] shows that the 0.5 percent CO_2 level will not be exceeded if 3 cfm of fresh air is supplied to each shelter occupant. The calculations also show that this ventilation rate will keep the oxygen concentrations well within tolerable limits. Ventilation research by Wright and others has shown that in most shelters natural ventilation alone will consistently supply ventilation at a rate of 3 cfm per occupant or more [23,26,36] if there are exterior openings in the shelter structure. If the shelter must be occupied in a sealed or closed condition, ventilation will not be available and other means must be used to maintain CO_2 and oxygen levels within tolerable limits.

MRD Division, General American Transportation Corporation conducted a study to identify and evaluate various techniques of environmental control in closed shelters [71] and followed this study with experiments to test the more promising control systems [72]. Recommendations from these studies are that pressurized gas cylinders be used to store and supply oxygen and that baralyme (or soda lime) be used to remove CO_2 from the environment.

Carbon monoxide (CO) is another potential chemical contaminant in the shelter environment. Small quantities of CO are produced by human metabolism, but the volume is so small that it is unlikely ever to reach toxic levels. CO may be released into a shelter from any combustion, including internal combustion engines and smoking. One of the more likely sources of CO and other toxic gases in shelters is from adjacent or nearby fires that may be initiated by a nuclear attack. Several researchers have investigated this source of toxic gases. The experimental fire studies conducted by Waterman [12,13] found that a gas-tight barrier or a positive pressure in the shelter was needed to prevent toxic gases from migrating into the shelter from adjacent fires.

Scientific Services Incorporated reviewed the literature on the subject of toxic gases from mass fires [73] and concluded that little quantitative data are available. However, there is qualitative evidence from a review of historical incidents of mass fires that carbon monoxide, lack of oxygen, and other toxic gases and smoke have contributed to or caused death to shelter occupants [74].

The MRD studies cited above [71,72] indicate that carbon monoxide and methane can be controlled by catalytic combustion or Hopcalite units and that higher molecular weight contaminants can be removed by activated carbon. Positive pressure inside a shelter has already been mentioned as a means of preventing toxic gases from entering shelters from external sources. In 1965, the Franklin Institute Research Laboratories developed a manually powered blower that could be used to maintain a positive pressure in shelters [75]. The blower is a positive displacement type with a capacity of 112 cfm. A source of uncontaminated air is essential to the successful use of the device.

The previously cited study by Thomas A. Edison Research Laboratory [67] identified and evaluated instruments for monitoring a shelter chemical environment. Chemical constituents considered include oxygen, carbon dioxide, carbon monoxide, nitrogen dioxide, and explosive concentrations of hydrocarbons.

3. Biological Environment

In considering the shelter's biological environment (i.e., the presence or absence of pathogens, allergens, and vermin), the principal concern is with the manifestation of biological elements in the form of communicable disease outbreaks. If they occur, such outbreaks could debilitate a substantial portion of the shelter population and increase mortality among high-risk individuals, such as the very old or young or persons with preexisting health conditions. Of secondary importance are other consequences of the biological environment, such as insect bites and stings and allergic reactions. Thus, in reviewing the current status of the biological aspects of shelter habitability, the emphasis is on assessing the communicable disease potential and identifying methods of controlling disease outbreaks.

The following discussion of the biological environment is divided into three categories:

- Civil defense research (i.e., by the Office of Civil Defense, the Defense Civil Preparedness Agency, and the Federal Emergency Management Agency)
- Disaster-related health studies (other than civil defense studies)
- Research (not disaster related) on communicable diseases and allergens.

Although some of the literature reviewed and included here does not specifically address shelter habitability, it is considered important in understanding the biological elements that might impact shelter habitability.

a. Civil Defense Research

Several civil defense studies have examined the likelihood of communicable disease outbreaks following nuclear attacks, both in sheltered populations and in the surviving population in general. These studies have concluded that those diseases occurring normally in the U.S. population are also likely to occur during and after a shelter period and that other elements of the shelter environment, such as space and sanitation, can be expected to alter the transmission of these diseases.

In studying the health problems following a nuclear attack, Herzog [76] stated that infectious diseases will be the principal health hazard associated with crowded shelters, with respiratory diseases being the most important followed by enteric, arthropod-borne, and venereal infections. According to Herzog, respiratory infections would likely affect nearly all persons in shelters. Mild infections such as the common cold can be expected to occur in almost all shelters, and more serious respiratory infections such as meningoccal meningitis, hemolytic streptococcal infections, influenza, and staphylococcal infections will occur in many shelters. Some serious infections resulting in fatalities will occur primarily among the very young and the elderly. Tuberculosis was not expected to occur to any great extent until after the shelter period, assuming a 2-week shelter period. Enteric diseases expected to pose a threat to shelter occupants include diarrheal diseases such as shigellosis and amebic dysentery [76]. Enteric diseases were expected to become more likely as sanitation practices deteriorate. Arthropod-borne diseases were not expected to present a problem during a 2-week shelter period, except that poor personal hygiene was expected to promote louse and flea infestations, possibly leading to post-shelter outbreaks of epidemic typhus fever and plague in some parts of the country [76]. Long latency periods and shelter discipline were expected to prevent venereal diseases from becoming an immediate problem. The overall number of deaths due to infectious disease during the shelter period (first 2 weeks after an attack) was predicted to be less than 1 percent.

Among the diseases of man, only the bacterial, protozoal, and viral diseases were considered by one study to have the post-attack potential for increase; fungi and parasitic worms were not thought likely to be important [77]. The report maintained that, although post-attack conditions might favor an increased incidence of some diseases (perhaps as much as an order of magnitude greater than usual), it was very unlikely that conditions would favor major epidemics such as have occurred in the past. The major constraints against such epidemics were listed as follows:

- Widespread public awareness and practice of the fundamental principles of sanitation

- Advanced diagnostic techniques permitting early identification of potential threats, which, in turn, makes it possible to mobilize resources where they can be used most effectively

- Artificial barriers such as vaccination, sewage treatment, water sterilization, government monitoring of commercial food processing, deliberate suppression of disease vectors (i.e., mosquitoes, rats, etc.)

- Medical countermeasures: hospitals, antibiotics, etc.

- Natural physiological resistance.

Judged by the author on the basis of infectiousness, appropriate modes of transmission and high mortality, the diseases having post-attack epidemic possibilities for humans fall into the following categories:

- Diseases that might conceivably overwhelm all efforts to control them, given a favorable situation such as a population with low resistance and overstrained medical facilities. The general requirements would be a high rate of infection, direct transmission (easy communicability), little or no immunity, and high mortality. The prime candidates were stated to be smallpox, cholera, diphtheria or, conceivably, some virulent new strain of influenza.

- Diseases that might erupt as a result of specific post-attack conditions such as breakdowns of sewage disposal systems, chlorination of public water supplies, pasteurization of milk, general sanitary precautions in the food processing industry, etc. Typhoid, paratyphoid, dysentery and infectious hepatitis were cited as the most likely threats. Plague was mentioned as another possibility. In very crowded quarters, such as fallout shelters, with inadequate facilities for personal hygiene, typhus outbreaks (transmitted by the body louse) were noted as being a distinct possibility. The reestablishment of U.S. reservoirs of malaria, yellow fever, dengue fever, and encephalitis--transmitted by Anopheles, Aedes and Culex mosquitoes, respectively--was also cited as possible.

The Division of Health Mobilization of the Public Health Service undertook a study to determine the nature and extent of acute and chronic illness within the population that would be cause for medical concern in the shelter environment [78]. The scope of work included a determination of acute and chronic illnesses that would be adversely affected by high temperature, high humidity, lowered oxygen, and restricted water and food intake. The study concluded that data were lacking on the effects of shelter confinement on persons afflicted with various health conditions, including communicable diseases. Variables were identified that would influence the mix of population groups entering shelters at the time of an attack. The time of year as well as years of high disease prevalence were variables identified that would influence the incidence and prevalence of acute respiratory diseases, such as influenza, and thus influence the prevalence of such diseases in the population entering shelters. The report noted that respiratory diseases, such as influenza, and enteric diseases, such as dysentery and common diarrheas, could spread under shelter conditions.

A 1967 study [79] evaluated the magnitude of acute intestinal disorders in human shelter occupancy and other confined space studies for their implications in fallout shelter habitability. No evidence was obtained showing that acute intestinal disorders, particularly diarrhea, would present a major problem. The study noted, however, that under a real shelter situation, more intense emotions of fear and anxiety could produce a high frequency of gastrointestinal symptoms.

Another study [80] identified enteric diseases that might reach epidemic proportions during a 2-week shelter period. Viral gastroenteritis, shigellosis or bacillary dysentery, and paratyphoid B fever were identified as most likely to be in-shelter problems. These diseases can be transmitted by the contact route, which becomes very important in a crowded shelter environment. While in-shelter epidemics of amebiasis, infectious hepatitis, and typhoid fever are not likely due to their long incubation periods, the in-shelter period provides an ideal setting for the transmission of these diseases resulting, possibly, in post-shelter period epidemics. Foodborne disease outbreaks are unlikely unless food preparation is undertaken in place of using prepackaged foods. Likely agents of foodborne disease outbreaks include Salmonellae, Staphylococci, and Type A Clostridium perfringens.

A 1968 study [81] examined the potential post-attack threat from vectorborne diseases during the first year following a nuclear attack. Although it did not specifically address the threat to shelter populations, some of the findings are applicable. Among the vectorborne diseases identified as being a threat to the general population following a nuclear attack, plague (in pneumonic form) and epidemic typhus were noted as being easily spread under conditions of crowding and poor hygiene. Poor hygiene caused by lack of bathing water and crowding are likely during a lengthy shelter period.

Respiratory diseases likely to cause post-attack problems in the United States were identified by other civil defense research [82] in the following order of probable occurrence: influenza, pneumonia, diphtheria, whooping cough (pertussis), measles (rubella), scarlet fever, meningococcal meningitis, and smallpox. These diseases are transmitted primarily by inhalation of airborne droplets containing the causative infectious microorganism and their attack rate is largely determined by the rate of contact between infected and susceptible populations. Crowding and reduced ventilation influence the rate of contact and are associated with greater attack rates for respiratory diseases. Although this study was concerned with the post-attack period including and beyond the in-shelter period, it is safe to assume that conditions during the in-shelter period are likely to be favorable to the transmission of the diseases it identified.

Mitchell [83] presented guidelines for dealing with 45 communicable diseases during pre-attack and post-attack time periods. The author emphasized diagnosis and antibiotic therapy and developed a strategy for working in more austere medical surroundings for each disease. Nutrition was considered to be of highest importance regarding resistance to infection. He recommends the use of broad coverage agents or a combination of agents where differential diagnosis is based solely on clinical diagnosis which will be the case for a large segment of the population since diagnostic laboratories may be inoperable or less accessible. Mitchell used two priority classification schemes based on disease severity and incidence to rank-order the 45 diseases.

In a study of the health and medical problems likely to occur during a 2-week crisis relocation period, during which time there is no nuclear attack, the problem of communicable disease outbreaks was addressed [84]. It was noted that during crisis relocation, those conditions, including communicable diseases, that occur under normal circumstances would continue to occur. In addition, populations relocated from high-risk areas into shelters in host areas during a pre-attack period may experience a greater than normal incidence of communicable diseases. This is likely where crowding and unsanitary conditions prevail. Many of the buildings to be used for sheltering risk-area evacuees will lack sufficient water and/or water distribution points, sewage disposal facilities, food handling facilities, and garbage collection and disposal facilities. Where the shelter sanitation facilities are inadequate and the number of people sheltered results in crowding, the shelter environment may deteriorate, with an increased likelihood of increased incidence of certain communicable diseases. The diseases identified as being of major importance for crowded populations in host-area shelters include food poisoning, sewage poisoning, nonspecific diarrheas, and, to a lesser extent, infectious hepatitis, shigellosis, and influenza.

To assess health-related problems following a nuclear attack and ability of survivors to perform certain jobs, computer simulations have been developed, including one to simulate communicable disease epidemics from days 31 through 365 after an attack [85]. Estimates of morbidity and mortality for 11 communicable diseases were made for two hypothetical areas using input data on survivors, physicians, and medical supplies. For each disease, several parameters were considered: susceptible population, infective population, contact rate, fraction of persons exposed to infection that become infected, duration of infectivity, type and daily requirement of medical supplies, and seasonal correction factors. The propagation rate of each disease was estimated with exposure to radiation, season, and geographic region taken into account.

Other crisis relocation planning studies have investigated the availability of shelters for fallout protection in host areas and methods of improving these shelters from the standpoint of water supplies and waste disposal for the purpose of preventing disease outbreaks. Recent studies of underground mines and large and small facilities included plans for implementing water supply and waste disposal systems for purposes of life support and communicable disease control [86,87,88].

In 1978, the capabilities of federal and state public health laboratories to provide diagnostic microbiology support for communicable disease control efforts following a natural disaster or a nuclear attack and during crisis relocation were examined [89]. Diseases considered to be potentially significant as a post-attack problem, a crisis relocation problem, or a problem following a natural disaster would include almost any disease endemic to the United States. Diseases identified as potentially significant post-attack problems were those identified in earlier civil defense studies [78,79,80]; however, it was noted that, if the same studies were performed today, the resulting diseases of significance would be different. For crisis relocation, diseases identified as being significant include food poisoning, hepatitis A, influenza, nonspecific diarrhea, and shigellosis.

A study published in 1979 examined the likelihood of recovering from a nuclear attack as well as the obstacles to overcome in a recovery [90]. The authors concluded that in the aftermath of nuclear war, there would be little chance of devasting and widespread epidemics of communicable diseases. However, the study did not address the communicable disease potential during the in-shelter period.

The impact of government policies on several key issues in post-attack recovery has been investigated [91]. In the area of health care, a crisis relocation program was seen as beneficial in reducing casualties and, therefore, the demand for medicines and medical personnel. The danger of epidemics was recognized especially, if an extended shelter period is necessary or if post-attack reorganization is prolonged. Epidemics were considered likely for the following reasons:

- Inadequate medical supplies and disruption of their distribution
- Improper nourishment
- Stress due to weather or working conditions
- Disproportionately high mortality for health care personnel
- Declining sanitation in crowded areas
- Improperly attended corpses of people and animals
- Inadequate water supplies.

In many of the civil defense studies discussed thus far, numerous alternatives for the prevention and control of communicable disease outbreaks in and out of shelters have been identified. Maintenance of sanitary conditions has been identified in several studies as a highly important preventive measure in controlling diseases [76-81,83,84,86-88,91]. In a post-attack period, enteric diseases such as shigellosis, amebiasis, infectious hepatitis, and typhoid fever are likely to be best prevented and controlled by good sanitation, including effective excreta disposal, provision of pathogen-free water, proper food handling, control of fly breeding, and personal hygiene [80]. Sanitation measures seen as necessary for the post-attack prevention and control of vectorborne diseases include, for plague and murine typhus, the elimination of rodent harborage and food in the vicinity of people, and the use of rodenticides and insecticides (to control rat fleas). For epidemic typhus, measures include delousing with insecticides and treatment of clothing by heat (boiling) or exposure to cold. For mosquito-borne encephalitis, measures include sanitary disposal of refuse, drainage of standing water, control of sewage effluent, and use of insecticides [81].

During crisis relocation and prior to a nuclear attack, communicable disease outbreaks are still considered possible [84]. Necessary sanitary functions identified for the prevention and control of communicable diseases in both host and risk areas include health and sanitation inspections of shelters, water supplies, food supplies, sewage systems, and garbage disposal systems; ensuring adequate public health personnel and supplies; surveillance of communicable diseases; and provision of veterinary public health services [84].

Guidance has been prepared for upgrading water supplies and waste disposal systems in mines and buildings that may be used as fallout shelters

[86,87,88]. Recommendations by these studies for potable water per day per shelter occupant ranged from a minimum of approximately one quart, which agrees with the Federal Civil Defense Guide (FCDG) [92] up to 5.3 gallons, based on a World Health Organization report [93]. Where existing shelter water supplies are likely to be inadequate, the following additional sources have been identified:

- In mines [86]:
    - Drilled wells
    - Springs
    - Tanker truck (in or outside the mine)
    - Storage containers
- In buildings [87,88,92]:
    - Protected wells (outside the building)
    - Storage containers
    - Tanker trucks (outside the building)
    - Fire control tanks
    - Sprinkler systems
    - Hot water heaters
    - Supply pipes
    - Holding and gravity tanks
    - Toilet flush tanks
    - Air conditioning or chilled water systems
    - Heating tanks and systems
    - Indoor swimming pools
    - Hydraulic elevators using water
    - Reflector pools (inside the building).

The requirement for excreta disposal was assumed to equal the per capita physiological requirements for water, 84 ounces per day, in one study [86], while in another the amount was given as 45 ounces per day [87] based on data for a standard adult man and adult woman [94]. The FCDG recommends 2.1 gallons of human waste disposal capacity per shelter space stocked [92]. This amount is equivalent to approximately 19 ounces per occupant per day and is considered by two reports [86,87] to be the minimum amount for planning shelter sewage disposal capacities. A desirable number of toilets in shelters was estimated at 7 per 100 occupants [86,87] and was based on Occupational Safety and Health Administration (OSHA) regulations for temporary labor camps. The FCDG recommendaton of 2 toilets per 100 occupants was viewed by one study [82] as the absolute minimum allowable and as probably adequate by another [87]. A variety of sewage disposal methods were presented [86,87], the appropriate methods depending on several factors such as type of shelter (mine, tunnel, or building), level of radioactive fallout, and available construction materials.

For purposes of planning for the disposal of shelter solid waste, one study assumed the normal daily per capita production of solid waste at 7 pounds [86]. In considering the limited resources likely to be available during a shelter period, another report [87] gave a more conservative and probably more realistic estimate of 1.5 to 2.5 pounds of solid waste per capita per day. There are no FCDG recommendations concerning solid waste quantities. It was recommended that 15-to 25-gallon-capacity containers be positioned at a rate of 3 to 4 containers per 100 occupants for the collection of solid waste. Several solid waste disposal techniques are available depending on the type of shelter, fallout levels, and available materials [86,87,88].

Another study [91] regarded the maintenance of high sanitation standards as the most important health preparation function for extended shelter periods in a crisis relocation. Fulfilling this need was seen to be assisted by providing the public with information on shelter sanitation practices, thereby encouraging them to participate in stockpiling available sanitation supplies in the host areas. After the relocation, the selection and training of a shelter sanitation specialist for each shelter group was recommended. A do-it-yourself book in each shelter, emphasizing appropriate emergency aid for radiation sickness, burns, respiratory, and a few communicable diseases, would increase the effectiveness of paramedical attention. It was recommended that each shelter also contain an adequate amount of written information on the control of insects and rodents.

The suitability of flush toilets for excreta disposal in shelters has been examined, as well as the availability of alternative systems [95]. The authors concluded that water requirements for flushing (approximately 4 gallons) were excessive and that steps could be taken to reduce the required amount, such as bending the float rod or flushing the toilet with a bucket of water. Among the alternative excreta disposal systems considered were the dual-purpose container (empty drinking water drum), anaerobic contact system, sanitary vault, individual disposal bags, and hand-operated recirculated waste disposal system. The dual-purpose container was preferred over the sanitary vault and the other systems. Methods identified for odor control and diseases include treatment of wastes with combinations of the following chemicals:

- Cupric sulfate, sodium bisulfate, and mineral oil
- Saponified cresylic acids and mineral oil
- Boric acid, sodium perborate, and mineral oil.

Quantities of human waste generated per person per day were identified to aid in planning. The quantities ranged from 0.13 to 0.6 gallons per person per day.

A textbook on the engineering aspects of fallout shelter habitability presented information on both shelter water requirements and shelter sanitation requirements [96]. Potential sources of water were identified and their potability discussed. Methods identified for disinfecting water included boiling, chemical disinfection (e.g., with chlorine), and filtering. The problem of large space requirements of barreled water storage in shelters was addressed. For example, instead of using potable water for hand washing after toilet use, a waterless hand cleaner followed by dipping the hands in a disinfectant solution was recommended. In addition, potable water could be conserved if nonpotable water was used to the extent feasible. It was suggested, for example, that nonpotable water could be used for bathing and showering and for waste disposal. Where water and sanitation supplies are stored in drums in shelters, these should be used for human waste disposal after they are emptied. Alternative methods for excreta disposal that were mentioned include the use of existing sewage systems where gravity will cause the waste to be carried away, and the use of manholes in protected areas. For waste disposal planning, 0.5 gallons per person was given as the likely amount of waste generated per day. The chemical treatment of waste was recommended to retard bacterial growth. The complete elimination of odors from sanitary facilities was considered unlikely; therefore, it was suggested that they should be located close to the ventilation discharge.

In a crisis relocation, host area populations are expected to increase severalfold. One result of this is that the amount of sewage that must be treated will increase. Citing the likelihood that host area sewage treatment systems will be overloaded and the potential for disease outbreaks increased, the problem of host area sewage treatment was examined in a 1978 study [96]. As part of the study, an emergency sewage handling manual was prepared which identified sewage-treatment operational problems likely during crisis relocation and presented a detailed troubleshooting guide to manage problems that arise.

In addition to sanitation, other prevention and control measures have been identified as important in the prevention and control of infectious diseases. Measures that have been recommended include adequate ventilation of shelters [82] in the case of respiratory diseases; availability of antibiotics, including their stockpiling in shelters, for therapeutic reasons and prevention of secondary infections [77,78,80,82-82]; immunization programs [77,78,80,83,84], although one study [82] regarded post-attack immunization programs as of little value; use of ultraviolet lights in shelters to control respiratory diseases [82]; disease surveillance [83,84]; nutrition [80,83]; diagnostic capabilities [83,89]; protection from radiation [80]; and public education [82,84,91].

Antibiotics and vaccines have been identified as important elements in controlling and preventing communicable disease outbreaks. The demand for drugs may be above normal in the post-attack period due to epidemics and large numbers of injured people, although the demand for drugs is high normally as witnessed by peacetime drug demand [97]. The importance of the pharmaceutical industry to post-attack recovery led to a study of the damage likely to occur to the industry from a nuclear attack [97,98]. Lifesaving drugs were identified and recovery strategies discussed.

b. Disaster-Related Health Studies

A series of studies of the biological and enviromental consequences of nuclear war was conducted for the U.S. Atomic Energy Commission (AEC) during the mid and late 1960s [99,100,111]. Plague was examined for its post-attack threat to survivors because it was considered highly virulent, because it was considered endemic in wild rodents in the western United States, and because a single case of bubonic plague could become pneumonic and start human-to-human spread involving potentially large numbers of people [99]. Pneumonic plague was noted as having special significance in the post-attack environment due to general stress and crowding inside shelters. Exposure to radiation was also cited as lessening people's resistance to disease in general, including plague. Increased exposure to plague-infected wild rodents was thought likely where civilians are relocated to rural areas, especially in western states. The study concluded that knowledge of the disease and its epidemiology along with existing methods of control and treatment make it highly unlikely that an epidemic of fourteenth-century "Black Death" proportions would occur; however, the possibility of epidemics could not be ruled out completely.

Another study in the same series for the AEC concluded that infectious diseases are likely to be very important in the post-attack environment [100]. The author felt that quarantines against cholera, plague, louse-borne relapsing fever, smallpox, yellow fever, and louse-borne epidemic typhus could fail in a post-attack situation and result in post-attack epidemics of these diseases. Because plague is endemic in the United States, a post-attack problem of sizable proportions was considered possible. Tuberculosis was described as being a potentially large problem given the large number of tuberculin positives in the population as well as post-attack hardships, such as exposure to radiation and poor housing. Acute respiratory diseases were also cited as being highly important in a post-attack environment given their high incidence rate and the likelihood of decreased resistance caused by stress and radiation from fallout.

The potential for a post-attack tuberculosis problem noted above was elaborated on in a 1967 study [102]. Factors cited that could exacerbate the peacetime tuberculosis situation include widespread dissemination of tuberculin positives in the population, malnutrition, inadequate housing and bad working conditions, injury, radiation exposure, crowding in shelters and work areas, migration of people, and breakdown of public health procedures. Preventive post-attack measures were discussed, including the use of chemoprophylactic agents such as isoniazid. BCG, a preparation containing nonvirulent live bacilli, was identified as the only available vaccine for tuberculosis, although its effectiveness was questionable. The author recommended that stockpiling of the necessary preventive agents be investigated.

A mathematical model of an infectious disease was used in another study to predict magnitudes of epidemics of communicable diseases in post-attack communities and to determine the effects of various curative and preventive measures on the epidemics [103]. The study was limited to a discussion of respiratory diseases, although the author stated that it may also have application to enteric and vectorborne diseases. The values of the model's two parameters, contact rate and host susceptibility, were determined by the disease under consideration, by the community concerned, and by several behavioral and environmental factors. Among the factors the author identified in the literature as affecting contact rate were the following:

- Crowding within a household--In more crowded conditions, the secondary attack rate of the common cold was greater than in less crowded conditions.

- Size of household--The size of household was independent of contact rate for the common cold.

- Relative humidity--Rhinoviruses and unspecified adenoviruses were reported to survive better suspended in the air at higher humidities, while higher humidities apparently reduced morbidity from respiratory infections. Thus, for relative humidity, the response of the host had a larger effect on contact rate then survival changes of organisms suspended in the air. Influenza type A was shown to survive better when the relative humidity was lower, 35 percent, than at a higher relative humidity of 65 percent.

- Temperature level--Attack rates of the common cold were found not to differ between a group of volunteers that was experimentally chilled and a group that was not chilled. The only associations noted were higher attack rates in chilled female volunteers in the middle third of their menstrual cycle, and a slightly higher attack rate in the summer than in the winter, expecially among male volunteers. Normal variations of indoor temperatures were reported to have a small effect on survival for influenza A.

- Temperature change--Evidence was cited for an increased attack rate by the common cold when outdoor temperatures drop.

- Season--Attack rates have been reported to be higher in the winter than in the summer for adenovirus type 4 and influenza A. Other factors, such as crowding, ventilation, concomitant pathology, etc., may have been responsible for the increased attack rates.

- Ventilation--Evidence was cited that increased ventilation decreases the contact rate for tuberculosis.

- Air pollution--A positive correlation between sulfur oxide content of the air and crude attack rate of acute respiratory diseases (mainly common cold) was cited; but the data were stated to be inconclusive as to whether contact rate or host susceptibility was primarily affected.

The factors that were identified as likely to influence host susceptibility included the following:

- Radiation--Radiation contributes to increased host susceptibility because it decreases antibody response, effectiveness of cellular defense mechanisms, and effectiveness of immunizing agents and increases hypersensitivity to antibiotics and susceptibility to toxins and, sometimes, harmful immunizing agents.

- Nutritional status--Evidence was cited for a strong association between nutritional status and nonspecific host resistance against bacterial disease, but not for an association with viral diseases. A distinction was also made between the effects of chronic protein malnutrition in underdeveloped countries and acute caloric malnutrition observed during periods of war. In the former, a clear association was noted between susceptibility to infectious disease and atrophy of host cells involved in the defense mechanism. In acute caloric starvation, rapid weight loss occurs but does not affect the body's nutrient consumption (which is derived in part from catabolism of the body's own tissue), and, unless a vitamin deficiency occurs, the susceptibility to infection is not greatly increased.

- Air pollution--Evidence was cited for a correlation between suspended sulfate particulates and the incidence of respiratory diseases.

- Emotional and genetic effects--These were mentioned as probably affecting host resistance.

An assessment of the communicable disease potential of disasters concludes that epidemics result frequently from the social disruption, crowding, and deficient sanitation following disasters [104]. In developed countries, the endemic diseases most likely to be affected following a disaster today are:

- Nonspecific diarrhea
- Food poisoning
- Shigellosis
- Infectious hepatitis
- Influenza.

The author states, however, that no study documents the effect that disasters have on these conditions. Clinical experience indicates that these diseases rarely cause post-disaster medical problems at higher than expected numbers. Therefore, the common practice of immunizing against typhoid, paratyphoid, and tetanus has no justification in economically advanced countries. The author recommends that following a disaster, communicable disease surveillance and investigation be instituted; public health services should focus on providing safe food and water and environmental sanitation; and vaccination programs against communicable diseases should not be undertaken.

A report prepared for the U.S. Arms control and Disarmament Agency evaluated post-attack medical and health problems, emphasizing the potential for communicable disease outbreaks [105]. The study reviewed earlier research on the post-attack communicable disease problem in an attempt to assess the vulnerability of the U.S.S.R. to epidemics. They concluded that, as in the United States, the possibility of serious post-attack communicable disease epidemics although perhaps remote, could not be ruled out.

A recent article in the New England Journal of Medicine examined the threat of communicable diseases to survivors of a nuclear war and described the problem as possibly the greatest threat to survivors [106].

In addition to trying to predict the nature and extent of post-disaster communicable disease problem, several studies have presented prevention and control measures. Again, maintenance of high sanitation levels were seen as being the most effective in combating disease outbreaks. Removal of food and harborage for rats, the use of rodent poisons, and the use of insecticides to control rat fleas were suggested for the prevention and control of plague in the post-attack period [99]. General sanitation measures, such as providing safe food and water and waste disposal, were identified as important against numerous other diseases considered to be important in the post-attack period [99,102,105] and after natural disasters [104].

Relief measures commonly employed to avert disease epidemics following natural disasters were recently reviewed with a view toward dispelling particular myths [107]. Mass immunizations to prevent epidemics of measles, cholera, and typhoid have been instituted in the recent past following flooding and earthquakes. The author maintains that there is little convincing evidence that such epidemics are likely or that mass vaccination is helpful in their prevention. Although necessary circumstances for disease transmission may exist, they may not be sufficient; in other words, it takes environment, host, and agent to produce disease. Another factor in the disaster-epidemic myth is that relief workers may encounter levels of diseases that appear high to them and as a result believe an epidemic is in progress when, in fact, the level is quite normal for that region. The same happens for water coliform levels, which may be normally high in a Third World country but seem alarmingly high to a sanitary engineer doing relief work. Expected seasonal increases in a disease may also coincide with a disaster and thus be falsely attributed to the disaster. The benefits of mass immunization campaigns were described as overrated. Reasons cited for this include inadequate coverage of the population, lack of potency of the vaccines due to inactivation by heat, requirements for two or more doses for some vaccines to be effective, and only partial protection conveyed by an immunization. Immunizations may have also had physical side effects due to disregard of sterile techniques and creation of a false sense of security leading to neglect of personal hygiene or other control measures. Another myth cited by the author is the belief that corpses transmit diseases, leading to epidemics. Actually, corpses transmit disease much less readily than the infected living.

Because diagnostic tools may be lacking, the use of broad spectrum antibiotics to treat a range of diseases was recommended in addition to producing sufficient quantities of these drugs during normal times [105]. Sulfa drugs and antibiotics for controlling the spread of the plague [99] and isoniazid treatment for the control of tuberculosis [102] in the post-attack period have been recommended.

Other measures that have been suggested include the maintenance of the external quarantine to prevent the entry into this country of diseases that are not now present, such as yellow fever and epidemic typhus, and the isolation of infected individuals [105].

c. Research on Allergens and Communicable Diseases

The emphasis in this section is on recent literature (other than civil defense and disaster-related literature already cited) relevant to the study of the biological elements of shelter habitability and to the current status of communicable disease in the United States including recent notable changes in the status of communicable diseases. Unless noted otherwise, the following discussion is taken from a review of indoor airborne contagion and allergens by the National Academy of Science [108]. Although not directed toward shelter habitability or post-disaster disease problems, some of the principles of disease transmission and prevention are relevant.

Acute respiratory infection, the greatest cause of morbidity, is transmitted by airborne organisms. The transmission from person to person is mostly an indoor phenomenon. Indoor airborne transmission of infectious agents is facilitated by the prompt dispersion of particles. In general, bacteria found inside buildings have indoor sources, primarily humans. The respiratory tract is the major source, although abrasion of the skin and showering increase the rate of loss of bacteria.

Droplet nuclei, the dried residues of the smallest respiratory droplets, range in size from 1 to 3 microns and disperse rapidly throughout the air of a room, being carried wherever the air goes. Infectious droplet nuclei originate from the human respiratory tract of people carrying the organism and, where the concentration of droplet nuclei is sufficient, person-to-person aerial transmission occurs. Contact with infectious organisms requires proximity in time and space between host and victim but can include a shared ventilation system if the air within the system is recirculated; the recirculating air then becomes a common enclosed atmosphere.

Studies carried out in a hospital showed that guinea pigs became infected after breathing air vented from a tuberculosis ward through ventilation ducts. On the basis of this and other evidence, it is generally agreed that the initial infection of the lungs with tuberculosis is by airborne transmission. Other studies have demonstrated the airborne route of infection. In schools in which ultraviolet (UV) air-disinfection fixtures had been installed, the incidence of measles among school children was much lower than in schools without the UV fixtures during a major measles epidemic, pointing to the reduction in concentration of airborne measles virus. In another school, a single case of measles resulted in 28 secondary cases among children who never met or even occupied the same room as the index case. The only common link was the schools' ventilation system, which recirculated about 70 percent of the air. Studies of outbreaks of influenza, smallpox, and other viral infections have given support to the droplet-nuclei concept of indoor airborne contagion.

Although infections in hospitals have not been shown to be primarily airborne, hospital-acquired (nosocomial) infections of the lower respiratory tract are presumptively airborne. Hospital patients are often hypersusceptible to infection, and transmission may occur in ways not often seen in the general population. A major epidemic of Legionnaire's disease occurred in a hospital into which outside air contaminated with <u>Legionella pneumophila</u> leaked during adjacent construction. This organism is unusual among bacterial pathogens in that it apparently exists in outdoor natural reservoirs (soils) and infection is possible through inhalation of contaminated outdoor air. The most common mode of spread of Legionnaire's disease involves air-cooling equipment that becomes contaminated and produces concentrated bacterial aerosols.

Air-conditioning and air-humidifying equipment can be a source of intramural bacterial aerosols. Cool-mist vaporizers and nebulizers can produce heavily contaminated aerosols and are of special concern. Other appliances reported to be potential sources of indoor bacterial aerosols are flush toilets. Ice machines are also potential foci for bacterial contamination. Carpeting has been discussed as a focus for bacterial contamination but can, in fact, reduce airborne bacterial concentrations by trapping bacteria-laden particles in the pile. There are specific sites at which bacteria may become airborne at high concentations. Factories that process organic materials may contain dense bacterial aerosols.

In some interior situations, even low bacterial concentrations are of concern. A submarine constitutes a closed system in which human-source bacteria could accumulate to an undesirable extent. However, it has been concluded that modern air-cleaning in submarines creates an environment unusually low in bacteria. Bacteria (both surface and airborne) in the hospital environment warrant attention. Bacterial content in a hospital environment depends primarily on the presence of humans and on the degree and types of their activity.

Bacterial products may contaminate indoor air in the absence of bacterial cells. Fine dust in a detergent factory was found to contain *Bacillus subtilis* enzymes. Workers became ill when exposed to sewage-sludge dust; the active factor was presumed to be airborne endotoxin. Finally, laboratory personnel illness has occurred as the result of inhalation of tuberculin aerosols during operation of a high-speed centrifuge.

Several fungi, including Blastomyces, Cryptococcus, Coccidioides, and Histoplasma, are all known primarily as human pathogens and exist in natural reservoirs, usually associated with bird or animal emanations. The extent of contamination of interior situations by these fungi is unknown. However, all are known to enter the body by the respiratory route, and Coccidioides and Histoplasma are known to be highly infective. Thus, natural reservoirs near human habitation will surely result in some interior contamination leading to a possible risk of infection. For example, 5×10^7 viable Cryptococcus spores have been found per gram of dry pigeon fecal material, and the spores were present in more than half the pigeon droppings examined.

The importance of airborne transmission of diseases was demonstrated in a 9.5-year study of 85 families in Cleveland, Ohio. The investigator found that 63 percent of all illnesses were respiratory. According to the National Health Survey, respiratory conditions (predominantly upper respiratory disease and "influenza") account for more than half of all acute conditions, including illnesses and injuries. The incidence of respiratory conditions is just under one per person per year, and, on an average, each person's activity is restricted for 4.5 days. If one grants that the respiratory conditions referred to are mostly in the category of indoor airborne contagion, the problem is seen to be enormous. Loss of time from work or from school exceeds that from any other cause.

The prevention of airborne infections has been helped by less-crowded living conditions, isolation, and vaccination. A preventive measure that is assuming increasing importance is air disinfection in buildings.

Control of epidemic spread of airborne contagion requires that each infectious case result in, on the average, no more than one new case. The concentration of infectious droplet nuclei must be reduced to the point where susceptible people stand but a small chance of inhaling an infectious particle. In relatively airtight buildings where the capacity of the ventilating system, the fraction of fresh-air makeup, and the efficiency of the filters are known; where the number of infections in each generation of an epidemic is available from records; and where the pulmonary ventilation and duration of exposure of the occupants can be estimated, the essential characteristics of airborne contagion can be dealt with quantitatively. In a 1974 measles epidemic in a school in New York, this was done. During the first generation, the number of infectious particles produced per minute in the index case was 93--an amount that produced a concentration in recirculated air of 1 per 5.17 m^3. Twenty-six susceptible children breathing this sparsely infected air acquired measles and appeared as cases in the second generation. Thus, the routes of transmission are airborne through infiltration and ventilation, from person to person, and via fomites*. The effects of ventilation rates are not quantifiable; however, increased ventilation necessarily dilutes the concentration of infectious organisms and could reduce transmission rates. There are interactions between microorganisms and pollutants, as between indoor combustion and smoking, in producing respiratory illness, especially in children and the infirm.

Only a few airborne allergens are found in enclosed spaces. Although human exposure to them is recurrent and of variable duration, the health effects of exposure to them alone are difficult to estimate. Despite this uncertainty, the impact of some agents is clearly appreciable. House dust and pollen, for example, are two of the most important factors in provoking symptoms of allergic rhinitis and asthma in many locales. Clinically evident

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* Inanimate objects that may be contaminated with infectious organisms and serve in disease transmission.

allergy to animal danders is due to both the popularity of house pets and the strong sensitizing capacities they exhibit. However, the contribution of other indoor exposures to the overall toll exacted by allergic diseases remains speculative.

Pollens, fungi, algae, actinomycetes, arthropod fragments, dusts, and pumices have been confirmed as airborne antigen sources that evoke human responses; evidence similarly implicating airborne bacteria, protozoa, and other groups is still emerging. Analyses of health impact are further complicated by the varied tissue responses that may be evoked, separately or in combination, by antigen challenge.

Particles recovered from indoor air often are assumed to have arisen within the enclosure studied. However, a large proportion of indoor particles reflect natural sources, especially when local growing conditions are favorable. Inward flux is especially evident for pollen, but also affects interior loads of fungi, insects, and algae [108].

Although there appears to be very little information in the literature on the effects of environmental factors on the occurrence of communicable diseases, it has been stated that death rates from almost all diseases are negatively correlated with temperature; that is, as temperature declines, death rate increases [109]. However, for pneumonia, there appears to be a short-term positive association with humidity and temperature so that patients, especially the elderly, having pneumonia should avoid high ambient temperatures and humidity [109]. Low temperatures and humidity seem to be positively correlated with the incidence of pneumonia either by favoring the acquisition of infection or resistance to it [109]. Possible explanations for the increased incidence of respiratory infections during the winter (colder) months include the following:

- Crowding and reduced indoor ventilation, which favor the spread of infection
- Low temperature, low humidity, and low ultraviolet flux, which favor survival of pathogens
- Low humidity, which can dry mucosa and reduce ciliary action, which favor infection
- Low temperature, which causes increased mucus secretion and favors transmission [109].

Mitchell [83] and Johnston et al. [89] concluded that communicable disease diagnostic capabilities would be reduced following a nuclear attack. Without such capabilities, differential diagnosis would be based solely on clinical diagnosis. Recently, a compact portable diagnostic kit was developed by the U.S. Navy for rapid diagnosis of infectious diseases under field conditions, i.e., without laboratory facilities [110]. It may also be used in public health surveys for asymptomatic carriers of pathogenic organisms and for serologic surveys. The capabilities of the kit include diagnostic microscopy, counterimmunoelectrophoresis tests, coagglutination tests, and culture tube incubation. The rapid diagnosis of a wide variety of infections caused by various pathogens is possible. The kit has been field tested and has been used to diagnose meningitis, cholera, and salmonellosis. This kit represents practical and appropriate technology and offers rapid and low-cost diagnostic and survey applications [110].

To determine the status of communicable diseases in the United States, two sources should be examined. One is the National Center for Health Statistics (NCHS) which, through the National Health Interview Survey, collects information on acute illnesses and injuries among the U.S. civilian noninstitutionalized population. The other source is the Centers for Disease Control (CDC) which, in its Morbidity and Mortality Weekly Report, reports the occurrence of notifiable diseases from reports submitted by state and territorial departments of health. The NCHS and CDC are the major sources of data on the nationwide occurrence of infectious diseases.

According to the NCHS, respiratory conditions during 1980 accounted for over one-half (52 percent) of all acute conditions, including illnesses and injuries [111]. The common cold and influenza were the most frequently occurring respiratory conditions. On an annual basis, respiratory diseases occur at the rate of approximately 116 cases per 100 persons. Table II-1 presents the incidence of respiratory and infectious diseases for the year 1980.

State and territorial health departments routinely submit reports on certain notifiable diseases to the CDC. Those diseases that are currently reportable are shown in Table II-2 along with the total number of reported cases and the reported cases per 100,000 population for 1980 [112]. Among the more notable trends in the occurrence of communicable diseases has been the dramatic decline in the incidence of German measles (rubella). Reported measles in the United States reached a record low in 1981, when a provisional total of approximately 3,000 cases were reported (1.3 cases per 100,000 population of all ages), as compared to the 1950-1962 prevaccine era, when an annual average of about 526,000 cases were reported (315.2 cases per 100,000 population) [113]. This low occurrence is due largely to a nationwide program aimed at the immunization of school children to eliminate indigenous measles from the United States. Mumps and rubeola have also reached record low levels due to the immunization efforts [112]. On a worldwide basis, efforts by the World Health Organization (WHO) resulted in the eradication of smallpox. The last known case occurred in Somalia in October 1977, with formal WHO-certified eradication in October 1979 [114].

TABLE II-1. INCIDENCE OF RESPIRATORY, INFECTIVE, AND PARASITIC DISEASES, PERCENT DISTRIBUTION, AND NUMBER OF ACUTE CONDITIONS PER 100 PERSONS PER YEAR IN THE UNITED STATES, 1980

Condition Group	Incidence of Acute Conditions in Thousands	Percent Distribution	Number of Acute Conditions Per 100 Persons Per Year
All acute conditions	484,159	100.0	222.2
Infective and parasitic diseases	53,580	11.1	24.6
Common childhood diseases	4,443	0.9	2.0
Virus, NOS	23,842	4.9	10.9
Other infective and parasitic diseases	25,294	5.2	11.6
Respiratory conditions	253,175	52.3	116.2
Upper respiratory conditions	124,218	25.7	57.0
Common cold	93,143	19.2	42.7
Other upper respiratory conditions	31,076	6.4	14.3
Influenza	113,799	23.5	52.2
Influenza with digestive manifestations	6,137	1.3	2.8
Other influenza	107,662	22.2	49.4
Other respiratory conditions	15,159	3.1	7.0
Pneumonia	2,454	0.5	1.1
Bronchitis	7,806	1.6	3.6
Other respiratory conditions	4,899	1.0	2.2

Note: NOS = Not Otherwise Specified.

Source: National Center for Health Statistics. Vital and Health Statistics. DHHS Publication No. (PHS) 82-1567. Hyattsville, Md. December 1981.

TABLE II-2. NUMBER OF CASES AND CASES PER 100,000 POPULATION OF REPORTED COMMUNICABLE DISEASES

Disease	Number of Cases	Cases per 100,000 Population
Amebiasis	5,271	2.38
Anthrax	1	0.00
Aseptic meningitis	8,028	3.61
Botulism, total	89	0.04
Foodborne	18	0.01
Infant	68	0.03
Brucellosis (undulant fever)	183	0.08
Chickenpox	190,894	96.69
Cholera	10	0.00
Diphtheria	3	0.00
Gonorrhea	1,004,029	443.27
Hepatitis A	29,087	
Hepatitis B	19,015	12.84
Hepatitis, unspecified	11,894	8.39
Legionellosis	441[a]	5.25
Leprosy	223	0.19
Leptospirosis	85	0.10
Malaria	2,062	0.04
Measles (rubeola)	13,506	0.09
Meningococcal infections	2,840	0.91
Mumps	8,576	3.86
Pertussis (whooping cough)	1,730	0.76
Plague	18	0.01
Poliomyelitis, total	9	0.00
paralytic	8	0.00
Psittacosis	124	0.05
Rabies, human	--[b]	0.00
Rheumatic fever, acute	432	0.30
Rubella (German measles)	3,904	1.72
Rubella congenital syndrome	50	0.01
Salmonellosis	33,715	14.88
Shigellosis	19,041	8.41
Syphilis, primary & secondary	27,204	12.00
Tetanus	95	0.04
Trichinosis	131	0.06
Tularemia	234	0.10
Typhoid fever	510	0.23
Typhus fever		
Flea-borne (endemic, murine)	81	0.04
Tick-borne (Rocky Mountain spotted)	1,163	0.52

[a] Includes sporadic cases only.
[b] No cases reported.
Note: Rates less than 0.01 after rounding are shown as 0.00.
Source: Centers for Disease Control. "Annual Summary 1980: Reported Morbidity and Mortality in the United States." _Morbidity and Mortality Weekly Report_ 29(54):1-17. September 1981.

For a few diseases, incidence has increased. The incidence of Rocky Mountain spotted fever (tick-borne typhus), for example, increased rapidly during the late 1960s and into the 1970s; the infection rate has remained about the same (around 0.5 cases per 100,000 population) since about 1977 [115]. The South-Atlantic states account for over 50 percent of the cases, with North Carolina, South Carolina, Oklahoma, and Virginia reporting most of the cases [113]. Reported cases of leprosy have also increased, but these reports represent imported cases (refugees) rather than indigenous transmission [112].

In recent years, diseases have appeared for the first time or have reappeared after being absent from the United States for many years. Legionnella pneumophila is now an established cause of pneumonia (legionnaires' disease, or legionellosis), having been first identified in Philadelphia in 1976. This infection is known to be associated with the presence of the organism in the environment, particularly in water from cooling towers and plumbing installations, although the organism has also been found in rivers, streams, lakes, and cooling towers with no known association with clinical infections [116].

Although cholera is endemic in areas, such as Bengal and Thailand, only one unexplained case occurred in the United States between 1911 and 1978 in Port Lavaca, Texas [117]. However, after the discovery of a case in Louisiana in 1978, investigations led to detection of 10 other infections transmitted from cooked crabs from Louisiana marshes and found evidence that the agent of cholera had persisted along the Gulf Coast for at least 5 years [117]. Another outbreak of cholera on a Gulf Coast oil rig was possibly the result of a cross connection between the rig's drinking water system and the canal water system used for drilling [118]. Although epidemics of cholera are not likely to occur in the United States because of high standards of sanitation and hygiene, occasional sporadic cases, without further transmission, can be expected; occasional outbreaks of several cases may occur when food and water sanitation are interrupted [118].

Between July 1977 and January 1980, seven cases of sporadic, "epidemic" typhus (Rickettsia prowazeki) were discovered in Virginia, West Virginia, and North Carolina [119]. A serious and often fatal disease, primary "epidemic" typhus was last reported in the eastern United States in Philadelphia in 1836. The southern flying squirrel appears to be a significant animal reservoir for R.prowazeki [119], previously considered an infection in humans with humans as the sole reservoir and lice as the only vector. Several cases diagnosed as Rocky Mountain spotted fever during winter months (most cases of Rocky Mountain spotted fever occur during April through September) have been caused by R.prowazeki [120]. Though it occurs, the illness is not occurring in epidemics, perhaps because of the absence of appropriate human vector ectoparasites; however, these aspects could change should circumstances permit the emergence of widespread Pediculus humanus corporis (body louse) in areas in which squirrel-borne "epidemic" typhus exists [119].

4. Other Considerations

As factors in shelter habitability, noise, lighting, and space have received minimal research attention. Environmental and occupational studies of these three factors are of limited use to shelter habitability, though noise and lighting are important components of work and residential environments. A sizable effort has been made to study light and human responses, and, due to energy costs, reduced lighting has recently been investigated for various work settings. Noise has also received considerable attention for persons exposed occupationally. Community nuisance noise levels have been studied for psychophysiological effects. The third factor, space, is closely related to noise and has been studied for its psychological or psychophysiological effects. Most space or crowding studies do not separate the thermal, chemical, and biological aspects of crowding.

a. Lighting

The requirements for shelter illumination were addressed in a study prepared by Smith and Wendel for the Office of Civil Defense, whose work tested the ability of persons to make visual judgments (acuity tests) under various levels of illumination [121]. Tests of mechanical and motor skills were also performed. Their work helped to establish shelter standards where simple tasks would be carried out. Non-civil-defense research has provided information that to some extent supports the low illumination standards developed for shelters. Highway safety research has studied related topics, such as eye adjustment to lights in the dark, illumination strengths for motor vehicles lights, and the mental-physiological components of visual acuity.

The greatest attention has been paid to the illumination requirements for occupational tasks. However, occupational tasks for which specific lighting needs have been determined (e.g., efficiency and accuracy) have a different set of lighting criteria than tasks expected under shelter conditions. No illumination level less than 1 foot-candle would be sufficient for industrial work, but shelter requirements can be met with illumination less than 1 foot-candle.

A potential problem of low illumination levels may be the psychological impact of minimal lighting in combination with other potential shelter environment stresses such as heat, illness, and lack of adequate food and water supplies.

b. Noise

The effects of sound have been studied outside of civil-defense-supported research. Despite tha fact that noise is a major occupational hazard, there is little information on the psychophysiological effects of noise by itself or in combination with other stresses. Possible effects of noise include permanent and temporary loss of hearing, cardiovascular disease, sleep disruption, and psychological effects [122]. In general, occupational and community noise problems are quite separate from shelter noise problems, although sleep disruption appears to be a relevant shelter issue. However, it is highly unlikely that the decibel levels expected in shelter environments are near the intensities that affect communication [123].

Noise and its behavioral effects can be controlled through group efforts. Social research into group dynamics has shown that numerous emotional stresses can be controlled through changes in behavior and informational intervention. Human and outside sources of noise can be similarly controlled.

c. Space

Psychological reactions to space are closely related to psychological reactions to noise. Historical studies of extreme crowding have shed some light on the effects of limited space. In nearly all cases, crowding is accompanied by other environmental stresses, such as heat, carbon dioxide, lack of sanitation, etc. However, by itself, crowding has some definite effects on humans. Uncomfortable feelings manifest themselves in a number of ways under group conditions. It has been found that male children, across all ages, show higher stress-related arousal than do female children [124]. In addition, prisoners show increased blood pressure with increased crowding [125].

A 1963 study for the Office of Civil Defense shows that there are social situations where people are comfortable in what would be defined as crowded conditions [126]. Theaters and night clubs have a much higher density than shelter and prison standards, for example, but their occupants remain comfortable because of relatively short periods of crowding and the maintenance of thermal and respiratory comfort, and their reason for being there.

Recent literature has addressed the issue of the psychological or emotional stress of crowding to a limited degree. Studies of natural disasters provide a framework for understanding the role that space plays in adapting to shelter environments. It is less critical, but as both civil defense and nonmilitary research has shown, space must be understood because of its relationship to environmental stresses such as heat, noise, air contaminants, and biological agents.

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III. SHELTER STANDARDS AND OCCUPANT RESPONSES

A. Shelter Standards

Standards established for fallout shelters are described in a Federal Emergency Management Agency (FEMA) publication entitled Standards for Fallout Shelters [1]. While there are many different standards for various aspects of fallout shelters such as radiological protection and structural integrity, this study is concerned only with those standards related to shelter habitability. Therefore, only those shelter standards that pertain to habitability are included in the following discussion. Underlying assumptions for this study are that shelters survive the initial attack, intact, and have adequate radiological protection.

1. Thermal Environment

Standards related to the thermal environment in shelters are stated as follows:

> Section 7.2. Effective Temperature. The fallout shelter shall have a ventilation rate sufficient to maintain a daily average effective temperature of not more than 82° F (28° C) with at least a 90-percent reliability of not exceeding that value during the year. Effective temperatures shall be determined using procedures contained in the Handbook of Fundamentals, 1977 edition, prepared by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE)...

> Section 7.4. Temperature. A temperature of not less than 50° F (10° C) shall be maintained in the fallout shelter during the occupancy period.

Maximum temperature is stated in terms of a daily average effective temperature at a level of 82° F. Effective temperature (ET) was originally selected as the unit of measure because of its widespread use by physiologists and because it was felt to be the most useful of the available thermal indices [2]. However, there is general agreement among physiologists and physicians that the ET scale gives inadequate allowance for humidity at high temperatures. Thus, a number of other thermal indices have been investigated as potential replacements for ET in shelter standards.

Other predictive schemes considered include the katathermometer, wet bulb-globe temperature (WBGT), operative temperature (OT), index of physiological effect (EP index), 4-hour sweat rate (P_4SR), heat stress index (HSI), relative heat strain (RHS), index of thermal stress (ITS), and physiological thermal index (PTI). In addition, a revised effective temperature, denoted ET^*, was developed. In a 1977 study, Pefley and MacDonald [3] compared the PTI (which Pefley had helped develop) with the ET and ET^* indices and concluded that the ET^* values are in error and should not replace the ET index until further study was completed. They also concluded that adoption of the PTI scale was a more satisfactory alternative. A more recent study by Lee [4] discussed each of the above indices, except ET^* and PTI. In that study, the author concluded that setting an exposure limit close to the maximum tolerable would involve great risk because of unforeseen variables that could cause more susceptible members of the group to be exposed over their physiological limits. He further concluded that the WBGT may be adequate to establish precautionary limits above which certain predefined precautions would be taken to guard against exposing individuals above their tolerance level.

A daily average of the ET was selected on the basis of data obtained from numerous simulated occupancy tests (see Section II). These data indicate that shelter ETs do not vary more than $\pm$ 2° F from the average during any one day. Available physiological evidence suggests that these small excursions from the average would not have a significant impact on the well-being of the shelter occupants.

Based on physiological data from a number of sources, a value of 82° F was selected as the limiting ET in a shelter. These data may be summarized in a general way as follows [2]:

1. Most elderly and sick people will survive ETs of at least 80° F.
2. Most children and middle aged people will survive ETs of at least 82° F.
3. Most healthy young men will survive ETs of at least 85° F.

While there is some disagreement among researchers concerning physiological effects at ETs of 80° to 85° F, most of the data indicate that a large majority of the population could survive for an extended period at a daily ET of 82° F.

The 90 percent reliability criterion was based on both economic and probability considerations [1]. If ventilation rates are set to achieve a very high probability (near 99 percent) of not exceeding the recommended ET, the costs of ventilation equipment escalate rapidly beyond the costs for a 90 percent probability. Radiological protection in shelters is set in the 90 to 95 percent range of probability that shelter occupants will not suffer severe physiological damage. An option available to shelter occupants if ventilation should prove inadequate is to abandon the shelter area or to spread out into less protected parts of the building. Such action would be dangerous only if the shelter is located in an area with sufficient fallout to cause illness or death from fallout radiation. The likelihood that shelters over the entire country would experience an intolerable environment during a given occupancy period is judged to be quite low, while the likelihood that in summer months some shelters would be in areas experiencing unusually warm weather would be significantly higher. Thus, injury or death would occur only in those instances where both hot weather conditions and heavy deposit fallouts occur simultaneously. The probability of this joint occurrence is considerably less than the probability that one or the other may occur. On the basis of this line of thought, a 90 percent ventilation reliability was judged to be reasonable from both economic and protective considerations.

At least one researcher has questioned the choice of 90 percent reliability of ventilation systems [5]. Weather data from four cities were used to calculate the maximum persistence of ETs greater than 82° F, and the additional ventilation required to reduce these persistences was computed. Because of the relatively long persistence times of the higher effective temperatures (48 to 235 hours), recommendations for increased ventilation rates were put forward. The recommended ventilation rates were up to three times as much as those for a 90 percent reliability criterion.

2. Chemical Environment

The shelter standard pertaining to the chemical environment is stated as follows [1]:

> Section 7.1 Fresh Air. A minimum of 3 cu. ft. of fresh air per minute per fallout shelter occupant shall be provided to prevent oxygen depletion and carbon dioxide buildup in the fallout shelter.

Although small reductions in oxygen concentration causes minor physiological effects, no serious effects occur until the concentration falls below 14 percent (from the normal concentration of about 21 percent). Battery powered submarines have an operating limit of 17 percent. If that level is used for fallout shelters, a ventilation rate of about 0.4 cfm per occupant would be adequate [2]. World War II experience in submarines and subsequent experiments with extended exposure to above normal carbon dioxide (CO_2) concentrations have established the necessity of keeping the CO_2 concentration at or below 1 percent. Both the Army and the Occupational Safety and Health

Administration (OSHA) have established permissible exposure limits for CO_2 at 0.5 percent. Using the respiratory requirements of a "standard man," 2.8 cfm of fresh air per person is required to limit the CO_2 concentration to that level. These considerations were the basis for the 3 cfm per person standard.

No other shelter standards were identified that relate to the shelter chemical environment. One research study reviewed identified numerous potential shelter chemical contaminants and investigated instruments that might be used for their detection [6]. However, no information was found relating to the probability that these chemical contaminants might actually be encountered in shelters.

3. Biological Environment

The only current standard related to the biological environment in shelters is one pertaining to sanitation. That standard is stated as follows [1]:

> Sanitation
>
> Section 13.0. Toilets, either flush-type operating from the normal water supply system, or chemical or other types, shall be provided on the basis of one toilet per 50 fallout shelter occupants. Toilets may be outside the fallout shelter in other portions of the building provided they may be reached by occupants of the fallout shelter without exposure to direct fallout radiation as defined in TR-20 (Volume 1), Shelter Design and Analysis--Fallout Radiation Shielding, June 1976 edition, available from the Federal Emergency Management Agency. Austere provisions, such as empty water containers, for disposal of waste may be considered as fulfilling this requirement.

While 1 toilet per 50 shelter occupants may suffice under the extreme emergency that would exist to initiate a period of shelter occupancy, other information sources indicate that a greater number is highly desirable. For example, the OSHA requires 1 toilet for every 15 persons in migrant labor camps [7]. The basis for the requirement in the shelter standard was not identified during this study.

4. <u>Other Considerations</u>

Items considered in this section include space, noise, and lighting. There are shelter standards relating to space and lighting but none relating to noise. The space and lighting standards are as follows:

> Section 5.3. Space. Space allowances for use as a fallout shelter shall be as follows:
>
> > (a) Floor Area. A minimum of 10 sq. ft. of net floor area shall be provided per shelter occupant. Partitions, columns, areas occupied by moveable furniture or other materials within the fallout shelter space, and any areas within the fallout shelter space used for storage of shelter supplies may be included in the net area.
> >
> > (b) Head Room. A minimum head room of 6.5 ft. shall be provided.
> >
> > (c) Volume. A minimum of 65 cu. ft. of net volume shall be provided per shelter occupant. Net volume shall be determined using the net area calculated for the space.
>
> <u>Lighting</u>
>
> Section 8.0 No special lighting is required for fallout shelters which receive natural light. Spaces without windows, above or below ground, shall be provided with a minimum lighting level of 2 footcandles at the floor. Normal lighting fixtures may be used for this purpose if they are powered by an emergency generator, or battery-operated lights may be used.

The 10 square feet of floor area per shelter occupant was selected based on the requirement of the average adult lying prone (i.e., sleeping position). The 6.5-foot minimum head room allows 99 percent of the U.S. population to stand upright [8,9]. Each of these criteria appears reasonable if life support systems are adequate. A study by Krupka in 1964 indicates that these figures could be reduced significantly if life support systems are also upgraded and suggests the shelters can be occupied at the rate of 3 square feet per person for extended occupancy and 2 square feet per person for short-term occupancy [10]. These suggestions are borne out by World War II shelter experiences.

The standard for lighting is based on that needed for moving around the shelter and performing general shelter tasks. While more lighting may be needed for special functions, such as medical treatment, occupancy tests have shown that most tasks can be accomplished at light levels well below 2 foot-candles. One test was successfully completed with no light at all [8]. However, at least some light in shelters is highly desirable.

B. Occupant Responses (Physiological)

1. Occupant Characteristics

a. Age, Sex, Race, and Urban-Rural

In 1980, there were approximately 225 million people living in the U.S. [11]. Of that total, 83.2 percent reported their race as white; 11.7 percent, black; 1.5 percent, Asian and Pacific Islander; 0.6 percent, American Indian, Eskimos, and Aleuts; and 3.0 percent other.

The age distribution of the U.S. population is presented in Table III-1. Less than one quarter of the population was under the age of 15 in 1980 (22.6 percent), and 11.3 percent was over the age of 64. The median age for males and females was 28.8 and 31.3, respectively. Females outnumber males by 116.5 million to 110.0 million (51.4 percent of U.S. total to 48.6 percent).

The 1980 census found that the proportion of the population living in urban areas was 73.7 percent, a level maintained over the last decade [12]. Regionally the U.S. population is distributed as follows [11]:

Northeast (ME, NH, VT, MA, RI, CT, NY, NJ, PA), 21.79 percent

North Central (OH, IN, IL, MI, WI, MN, IA, MO, ND, SD, NE, KS), 26.1 percent

TABLE III-1. AGE DISTRIBUTION OF U.S. POPULATION, 1980 (In Thousands)

	Population	Percent
All Ages	226,504	100
Under 5 years	16,344	7.2
5 to 14 years	34,938	15.5
15 to 24 years	42,474	20.1
25 to 34 years	37,076	19.4
35 to 44 years	25,631	11.4
45 to 54 years	22,797	10.1
55 to 64 years	21,700	9.6
65 to 74 years	15,578	6.9
75 to 84 years	7,727	3.4
85 years and older	2,240	1.0

Source: Reference 11.

South (DE, MD, DC, VI, WV, NC, SC, GA, FL, KY, TN, AL, MS, AR, LA, OK, TX), 33.3 percent

West (MT, IK, WT, CO, NM, AZ, UT, NV, WA, OR, CA, AL, HA), 19.0 percent

The urban-rural population distribution varies from a low of 66.9 percent urban in the South to 83.9 percent urban in the West [12].

Many demographic characteristics vary significantly from region to region, but, for purposes of this study, differences such as race have little bearing on shelter habitability. Age distribution may be of concern due to large numbers of older adults in Florida, for example. Other states with high median ages are concentrated in the northeast [11]. Percent of urbanization reflects the numbers of potential shelter occupants. Urbanization, in itself, does not contribute to shelter habitability problems. Rather, specific factors--such as number of sensitive persons being sheltered, shelter supplies, crowding, and the urban contribution to the chemical-thermal environment--profoundly affect shelter habitability.

b. State of Health

The health of the U.S. population can be characterized in a number of ways: (1) by the various conditions that exist or develop in a population, (2) by the degree to which individuals are restricted in activity, and (3) the degree to which individuals are dependent upon drugs, medical equipment, institutions, and daily attention from others to name a few. There would be great variety from shelter to shelter in the health needs of shelter occupants, but, overall, the health characteristics described below represent the U.S. population.

The health dynamics of the sheltered population during a 2 week or longer stay is far different from the daily changes in health found presently in the United States. To characterize the shelter population, it is useful to outline the expected chronic and acute conditions of the U.S. population entering the shelters. A 2-week period has been selected to identify the number of acute conditions that would have developed preceeding the shelter period. The prevalence of acute conditions at a given point in time is not provided in National Center for Health Statistics (NCHS) publications, so a 2-week incidence period is assumed to reflect the prevalence of acute conditions at time of entry for a shelter population. An acute condition is defined as a condition that lasts less than 3 months and that involves eith medical attention or restricted activity [13]. Certain conditions are defi as chronic regardless of the onset.

Acute Conditions

Table III-2 presents data on acute condition prevalences. Respiratory conditions would be expected to be the major acute problem found among a sheltered population, especially during the winter months [14]. Annually, 220 acute conditions develop per 100 civilian, noninstitutionalized persons [14].

This annual rate translates into 8.5 percent of the population developing an acute condition within a 2-week period, more than half of which would be respiratory conditions, or 4.5 per 100 persons. Many of the respiratory conditions and some of the infective-parasitic diseases, digestive system conditions, and other acute conditions increase the risk that biological, chemical, and thermal stresses would increase morbidity, and, possibly, mortality, among shelter occupants. This result is highly dependent upon seriousness of health condition and environmental stress:

> A condition is considered chronic if (1) the condition is described by the respondent (to National Health Interview Survey) as having been first noticed more than 3 months before the week of the interview, or (2) it is one of the following conditions always classified as chronic regardless of the onset: tuberculosis, neoplasms, thyroid gland disease, diabetes, gout, psychoses and certain other mental disorders, multiple

TABLE III-2. INCIDENCE OF ACUTE CONDITIONS PER 100 PERSONS BY CONDITION GROUP, U.S. PER FORTNIGHT[a]

Condition Group	Number of Acute Conditions per 100 Persons per Fortnight		
	Both Sexes	Male	Female
All Acute Conditions	8.5	7.8	9.2
Infective diseases	0.94	0.90	0.99
Common childhood	0.08	0.08	0.08
Virus, NOS[b]	0.42	0.38	0.46
Other infective & parasite	0.44	0.44	0.45
Respiratory conditions	4.5	4.0	4.9
Upper respiratory	2.1	2.0	2.4
Common cold	1.6	1.5	1.8
Other upper respiratory	0.5	0.5	0.6
Influenza	2.0	1.8	2.2
Influenza with digestive manifestation	0.1	0.07	0.14
Other influenza	1.9	1.7	2.1
Other respiratory	0.3	0.3	0.3
Pneumonia	0.04	0.03	0.05
Bronchitis	0.14	0.13	0.15
Other respiratory	0.08	0.10	0.08
Digestive System	0.43	0.43	0.43
Dental conditions	0.12	0.11	0.14
Upper gastrointestinal disorders	0.22	0.22	0.22
Other digestive system	0.09	0.10	0.09
Injuries	1.3	1.5	1.1
Fractures, dislocations, sprains, strains	0.36	0.56	0.36
Open wounds and lacerations	0.3	0.41	0.19
Concussions and superficial injury	0.26	0.26	0.26
Other current injuries	0.27	0.27	0.27
All other conditions	1.4	1.0	1.8
Diseases of the ear	0.36	0.35	0.37
Headaches	0.07	0.06	0.08
Genitourinary disorder	0.23	0.07	0.39
Deliveries and disorders of pregnancy, puerperium	0.08	--	0.15
Diseases of the skin	0.08	0.07	0.09
Diseases of the musculoskeletal system	0.14	0.12	0.16
All other acute conditions	0.43	0.37	0.50

[a] Source: Reference 14.
[b] Not Otherwise Specified.

sclerosis and certain other nervous system diseases, certain eye diseases and conditions, certain circulatory system diseases (includes rheumatic fever, hypertension, stroke, and all heart conditions), emphysema, asthma, hay fever and bronchiectasis, ulcers, abdominal hernia, gastroenteritis and colitis (with exceptions), calculus of kidney, ureter, and other urinary system parts, prostate diseases, chronic cystic diseases of the breast, eczema and certain other dermatitis, arthritis, rheumatism, bone cysts (except jaw), and all congenital anomalies [13].

NCHS chronic conditions data are organized by degree of activity limitation [15]. Table III-3 shows percent distribution of persons with no activity limitation, major activity limitation, and with any activity limitation by age and sex. As expected, persons 65 years and older have the greatest activity limitation. Men are consistently slightly more limited than women in activities.

It is difficult to determine the percentage of the identified chronic conditions that are risk factors in shelter habitability. Known conditions such as diabetes and circulatory diseases do reduce individuals' tolerance to heat stress, for example. Many chronic conditions may not increase physiological risk to environmental stresses but will likely increase the pressure on medical resources and attention required of other shelter occupants.

In addition to segments of the U.S. population identified as having acute or chronic (limitation in activity) conditions, certain persons not already identified should be considered at higher risk during shelter occupancy. Alcoholism, obesity, pregnancy and lactation, hypertension, and dependency on drugs are not likely to have been identified by the NCHS acute and chronic data presented in Tables III-2 and III-3. The following discussion will focus on those conditions.

TABLE III-3. PERCENT DISTRIBUTION OF PERSONS WITH LIMITATION OF ACTIVITY DUE TO CHRONIC CONDITIONS, BY DEGREE OF LIMITATION ACCORDING TO SEX AND AGE, 1980[a]

Sex and Age	Total Population (Percent)	Percent Distribution: With Activity Limitation	With Major Activity Limitation	No Activity Limitation
Both sexes				
All ages	100	14.4	10.9	85.6
Under 17 years		3.8	2.0	96.2
17 to 44 years		8.6	5.5	91.4
45 to 64 years		23.9	18.8	76.1
65 and older		45.2	39.0	54.8
Male				
All ages	100	14.7	11.2	85.3
Under 17		4.3	2.3	95.7
17 to 44 years		9.2	5.8	90.8
45 to 64 years		25.3	20.2	74.7
65 and older		48.8	44.2	51.2
Female				
All ages	100	14.1	10.6	85.9
Under 17 years		3.3	1.8	96.7
17 to 44 years		8.1	5.3	91.9
45 to 64		22.6	17.4	77.4
65 and older		42.7	35.3	57.3

[a] Source: Reference 15.

Notes

1. Major activity refers to ability to work, keep house, or engage in school or preschool activities.

2. Data refer to noninstitutionalized, civilian population.

One in 10 persons over the age of 15 who drinks is considered to be an alcoholic by the National Council on Alcoholism [16]. This ratio translates into 10 million alcoholics, or 4.4 percent of the total U.S. population.

As defined by the NCHS, obesity is a condition that affects 13 percent of all males 20 to 74 years of age and 23 percent of all females 20 to 74 years of age [17]. More black females are obese than white females, while black and white males are similar. The exact relationship between obesity and hypertension is unknown; however, obesity aggravates hypertension. Persons between 18 and 74 show hypertension rates of 18 percent [17]. Black adults have higher rates, between 28 and 29 percent, than do white adults. Approximately 16 to 17 percent of whites are hypertensive [17].

An estimate of the prevalence of pregnant women is made by adjusting the crude birth rate as reported by the NCHS [18]. In 1977, 1.54 live births occurred per 100 persons. Thus, approximately 1.5 women per 100 persons were pregnant at any given time in 1977 (adjusting for spontaneous and induced abortion, multiple births, 9 months of pregnancy, etc.) Therefore, 1.5 percent of the sheltered population would be pregnant. The number of lactating mothers is not well known; various surveys have made widely different estimates.

Dependency on drugs is another condition that may increase health risk during shelter occupancy. Drug supplies may not be provided in shelter stocks, and occupants would be required to bring their own supplies. Some drugs may require refrigeration. Drug abusers and addicts suffer psychologically and physically when drugs are not available. Many people using prescription drugs would be significantly affected by interruption of drug supplies. In the absence of additional shelter stress, approximately 7 percent of the U.S. population would be significantly affected if psychotropic drugs (antidepressants, antipsychotics, antianxiety) were not available [19]. Data on drug use have not been developed to describe the prevalence of all prescription drug use among the civilian, noninstitutionalized U.S. population. NCHS has conducted surveys of drugs prescribed by physicians (National Ambulatory Medical Care Surveys), but the information collected is not useful in characterizing the number of individuals requiring drugs at any time for health maintenance.

2. Responses at Standard Conditions

a. Normal Population

(1) Thermal Environment

A major concern of shelter habitability is the maintenance of the thermal equilibrium of shelter occupants. Physiological responses to heat continue to be studied both for the basic understanding of how man responds and acclimates to temperature extremes and for more applied reasons, such as protecting occupational groups and military personnel exposed to heat. Likewise, physiological responses to cold have and continue to receive considerable scientific attention.

Much of the research into physiological reactions to heat stress has involved healthy young subjects, typically male. Epidemiological research complements the laboratory research by investigating mortality and morbidity trends during adverse weather conditions. Both areas of research can be used to estimate the responses of a sheltered population to heat stress.

The current thermal standard for shelters is an average daily ET of 82° F. Use of the ET scale is suited for individuals who will move around a bit but who are not involved in heavy work [20]. The light air movement expected in shelters also corresponds to characteristics of the ET scale.

Humans respond to heat stress in a number of ways, including (1) dilation of blood vessels in the skin, (2) increased perspiration, (3) increased respiration, and (4) increased heart rate. These physiological adaptions contribute to increased heat dissipation. An important element in heat dissipation under stress conditions is the maintenance of a skin temperature around 35.6° C (96° F). Skin temperature reflects the amount of heat generated and the efficiency of heat dissipation [21]. Changes in circulating blood volume are made in the adjustment to heat stress. The degree and speed to which these physiological adjustments occur is highly dependent on acclimatization. An observation of D. B. Dill, a pioneer in heat research, is the increased ability of subjects to tolerate heat (in the form of increased perspiration) during the summer months relative to their ability in the winter months [21].

The normal population includes persons of varying degrees of heat (or cold) acclimatization. Physically active persons and persons who work in hot environments are better acclimated to heat stress [22,23,24]. Certain population groups such as the elderly, the young, those with cardiac and respiratory insufficiencies, and those individuals who are physically unfit are more sensitive to heat stress [25]. There are also sex differences in heat response. While exercising, heat-acclimatized females have lower evaporative cooling requirements in both hot-wet and hot-dry environments [26]. The notion that women do not tolerate heat as well as men has not been supported by recent research [27,28,29]. Epidemiological studies of heat-wave-related mortality and morbidity have given an unclear picture of the difference between the heat resistance abilities of males and females [30,31,32]. Major problems with epidemiological research into heat stress are the inability to control for exposure and levels of exertion, lack of autopsies by medical examiners, and the varying end points (mortality, morbidity, etc.) that were studied [33]. In the St. Louis heat wave of 1966, for example, there were equal numbers of male and female deaths, though more females had heat as a primary cause of death [31]. When heat illnesses were studied in New Orleans, 90 percent of the heat syndrome cases were male and 80 percent were of working age [30]. The conclusion drawn was that work under hot conditions is the major cause of heat related morbidity.

The extent to which populations are acclimatized is reflected in the type of response seen during excessively hot periods. New Orleans has a subtropical climate, and the general population is therefore somewhat acclimatized. Because New Orleans workers, typically male, add to the heat stress by physical exertion, they are the ones who are admitted to hospitals with heat cramps, heat exhaustion, heat asthenia, and heat stroke. The desert southwest population is partly heat acclimatized because of near year-round exposure to warm temperatures. It appears the midwest U.S. populations are most sensitive to heat stress because they are not exposed to high temperatures except from June through September [25]. Also, the largest cities in the Central Midwest, not the rural areas, show excessive heat illnesses because the cities themselves contribute to the excessive temperatures.

Heat acclimatization requires approximately 2 weeks of heat exposure [21]. The decay of acclimatization has been studied and is highly dependent on physical fitness levels. Different indexes used to measure acclimitization, such as heart rate and core temperature, yield different estimates of acclimatization decay [34]. The important point is that during fall, winter, and spring, large populations in temperate climates will not be heat acclimatized and, therefore, will be less tolerant of hot environments. Daily maximum temperatures of 100° F (38° C) have been associated with excess heat illnesses and deaths in St. Louis and Kansas City [25].

At standard shelter conditions there are likely to be uncomfortable occupants, but an ET of 82° F is not an extreme temperature. Above 75° F, sedentary people will be sweating to remove excess body heat, but the physiological strain is not excessive until skin and deep body temperatures rise.

Lind has indicated that deep bcdy temperatures should not rise at an ET of 82° F [23]. Though his and most other such studies have involved healthy young males, the subjects were studied under various work loads that would for the most part be higher than those expected for shelter occupants. A large shelter with bicycle powered generators for lighting could require levels of effort of approximately 60 to 100 Kcal per hour for those individuals turning bicycle pedals [35]. This is a level of effort at the lowest end of most exercise-heat stress tests. With adequate rest periods, shelter occupants should be able to tolerate light exercise regimes. Persons younger than 15 and older than 50 are less tolerant of heat because of inadequate sweating response [36]. At 28° C (83° F), all experimental subjects completed a 100-minute exercise under mild strain (30 to 35 percent of maximum oxygen volume [VO_2 30-35 percent]). Because most shelter occupants will be sedentary and because an 82° F ET is not an extreme temperature, the overwhelming majority of occupants should be able to tolerate extended periods of shelter occupancy in the absence of other shelter stresses.

The critical element will be water availability. The body has an ability to conserve water under strain, but basic water needs must be met for a sweating population. Approximately 4 liters (1 gallon) of water per day are needed for healthy persons to prevent dehydration [32]. In tests performed at Kansas

State University, dehydration did occur in subjects, male and female, ranging in age from 17 through 65, and exposed to an ET of 82° F. Water was restricted, and most tests involved standard civil defense rations. It was concluded that a daily ration of 1 3/4 quarts of water per person would prevent severe dehydration among a healthy population under a sedentary activity level. It would be safe to say that 1 3/4 quarts of potable water daily should be viewed as a minimum for an adult population under no additional stress. If persons are suffering from radiation exposure, additional water supplies would be required to replace water loss from diarrhea and vomiting [38]. Per capita consumption would naturally increase for the first week or so of a shelter stay due to acclimatization, which increases ones sweating volume, and, therefore, increases water (and salt) requirements.

Salt intake is important to the body's ability to cope with heat stress. Heat cramps are frequently caused by an imbalance of salt and water in body fluids and tissues. Although many modern diets contain excess sodium for daily needs, sweating could cause salt deficits under shelter conditions. The body is able to reduce the salt content of sweat (normally 30 to 540 mEq/liter) to as little as 2 to 5 mEq/liter in fully acclimatized people [39]. However, over the course of a few days on a reduced diet, salt supplements would be needed as body supplies are depleted.

Less critical to shelter survival are protein, vitamins, and calories. Healthy, nonactive adults can survive up to 2 weeks without protein and vitamins. The water content of foods would be useful in preventing dehydration, and the mineral content would provide needed sodium and potassium. Very young children and pregnant women require protein, vitamins, and mineral sustenance within a two week period. Illnesses and radiation sicknesses would place individuals in weakened states, requiring balanced foods to maintain or return individuals to health. Civil defense rations would provide adequate nutrition as long as food remains free of contamination and can be properly prepared.

The important concern of population variability in acclimatization and water-salt needs was voiced in a study by Stanford Research Institute (SRI) [40]. It was felt that in the late 1960s there still was insufficient information to estimate the range of population responses to an ET of 82° F. Since then, some non-civil-defense research has addressed population-wide variabilities in responses to heat stress, but questions remain regarding the expected population response to heat stress.

Shelter heat stress is not likely to be present in the absence of other environmental stresses. While an ET of 82° F is a mild stress, human responses would be aggravated by the presence of combustion products, radiation, or communicable disease. It is the combination of environmental stresses that is difficult to study and, therefore, has received little research attention. There appears to be a synergistic response to multiple stresses, though by no means have all the various stresses been studied in tandem or multiples. It is important to understand the potential for synergistic responses of a sheltered population. The maintenance of low levels of all environmental stresses will be required to maintain shelter habitability.

(2) Chemical Environment

A number of gases are likely to be found in the shelter environment at concentrations above background levels. Among them are carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile hydrocarbons (HCs). Also suspended in shelter air may be aerosols and particulates of organic and inorganic origin. Only CO_2 presently has a shelter standard.

The CO_2 standard of 0.5 percent is below the level at which studies have shown physiological or neurological changes. Nearly all the scientific studies relating CO_2 exposure to chronic effects have been performed with healthy, young, predominantly male subjects. Sensitive persons are those with chronic cardiac dysfunction, asthsma, and other pulmonary insufficiencies. They are discussed in Subsection III.B.2.b.

No study has yet shown that humans would not tolerate carbon dioxide levels of 0.5 percent given other (shelter) standard conditions over a projected 2-week period. The added stress of moderate exercise is apparently tolerated below 2.8 percent CO_2 [41]. The margin of safety between the 2.8 and 0.5 percent levels should be sufficient for nearly all shelter occupants. Shelter exercise requirements are expected to be minimal. A lack of physical fitness, per se, should have little bearing on the chemical habitability of the shelter environment at standard conditions.

The essential respiratory requirement is the maintenance of an atmosphere that allows for adequate oxygen to be absorbed and carried in the blood stream. A major concern for maintaining a chemically habitable shelter is pollutants resulting from combustion. In numerous urban areas, fires would continue to burn for days following weapon detonation and keeping the shelter nearly free of CO, NO_x, and other products of combustion would be very important. If a shelter is well sealed and a minimal air exchange is maintained, combustion products from shelter lighting or heating sources could build up to harmful levels.

Smoking is also a potential problem where space is minimal and reduced air exchange allows for CO buildup [42]. Buildup of CO and other pollutants from tobacco smoke could be a source of physiological and psychological stress. Tobacco smoke irritates the eyes, nose, and throat and is annoying to nonsmokers even in the presence of "adequate" ventilation. Coupled with other shelter stresses, tobacco use would likely be one of the more easily controlled shelter problems because it is controllable through voluntary actions. Exposure to combustion products from external fires is not so easily controlled.

"Sixty-eight percent of all fire related deaths, other than direct burns, generally have been attributed to CO poisoning or suffocation" [43]. Though no shelter standards exist for combustion products other than CO_2, combustion products at irritating or harmful levels are considered as nonstandard conditions (see Subsection III.B.3).

A relevant question is the potential synergistic effect of chemical pollutants at standard conditions when added to the psychological and physiological stresses of heat, biological agents, crowding, etc. For the normal population, no adverse effects are predicted at standard chemical conditions even with possible synergistic reponses to shelter elements.

(3) <u>Biological Environment</u>

As outlined above, there will be acute and chronic conditions among the sheltered population. Some individuals will also be carrying diseases, such as infectious hepatitis, and various dysenteries, that may not be reflected in the NCHS acute data (see Table III-2). It is the potential for outbreaks of communicable diseases that is a major concern during a shelter period. The shelter period will likely contribute to increased disease rates for certain diseases following the shelter period, e.g., tuberculosis, amebiasis, typhoid and hepatitis, because these diseases typically have incubation periods longer than 1 week. Therefore, persons contracting these diseases will not show symptoms until after the shelter period: tuberculosis, 4 to 12 week incubation; amebiasis, 2 to 4 week incubation; typhoid, 1 to 3 week incubation; hepatitis, 2 to 7 week incubation. A number of identified stresses--i.e., radiation, crowding, minimal ventilation, high humidity, water, sanitation, and nutritional shortfalls--contribute to increased susceptibility and spread of disease and infections.

(a) Communicable Diseases

Respiratory infections are the most common and troublesome of human infectious diseases. Usually mild, respiratory conditions may become serious under shelter stresses. Infectious agents spread rapidly under crowded conditions. In shelter trials under conditions considered less stressful than those expected during an actual shelter occupancy, respiratory infections developed in 50 percent of the subjects (healthy male adults) during a 2-week winter trial and in 79 percent of subjects during a 2-week summer trial [44]. It is expected that nearly every shelter occupant would develop respiratory conditions, whether mild or severe [45]. The most likely respiratory problems would be the common cold, meningococcal meningitis, streptococcal infections, influenza, and staphylococcal infections. Seasonal variations in incidence of respiratory disease will play an important role in shelter period respiratory problems, particularly for influenza. The common cold and adenovirusus infections increase the susceptibility of developing pneumonia, streptoccal infections, and other more serious respiratory problems as secondary infections. There will be epidemic outbreaks of acute respiratory infections in some shelters, but predicting the number of outbreaks is nearly impossible.

The extent of radiation damage to the body's immune response system is dependent upon dose. Any reduced ability to fight infection will cause increased rates and severity of communicable disease. A dose above 100 rems--a level above which a large portion of the U.S. population (approximately 50 percent) would be exposed--causes lowered resistance [45]. The inability to maintain present sanitary levels would constitute the second most serious acute problem following respiratory disease. Shelter conditions will aid the spread of infections, both bacterial and viral. Persons will be exposed to agents through the gastrointestinal tract that will cause enteric diseases found in the U.S., but not commonly experienced by Americans. Among these diseases may be infectious hepatitis, amebiasis, viral gastorenteritis, salmonellosis, shigellosis, and possibly typhoid and paratyphoid [46,47,48]. There exist enough carriers of the diseases mentioned above, except for typhoid and paratyphoid, in the U.S. population to create a potential for outbreaks of gastrointestinal diseases during shelter occupation. The annual reportable communicable diseases incidence for those diseases of post-attack importance are presented in Table III-4. The enteric diseases --amebiasis, hepatitis, salmonellosis and shigellosis--show the highest incidence among reportable communicable diseases. Not reported to and by the Centers for Disease Control (CDC) are paratyphoid and food poisoning by Clostridium perfringens, which have been identified as potentially significant in the post-attack period. Smallpox and diphtheria have been identified as potential problems, but, with the worldwide removal of smallpox and the reduction of U.S. diphtheria to 7 cases in the past 2 years, these two diseases could be considered as nonsignificant for the post-attack period. Scarlet fever and streptococcal sore throats have not been reported by CDC since 1969. Respiratory disease morbidity caused by influenza and pneumonia are not

TABLE III-4. REPORTED COMMUNICABLE DISEASE INCIDENCE FOR DISEASES OF POSTATTACK IMPORTANCE, U.S., 1980. ANNUAL

Disease	Cases Per 100,000 Population
Amebiasis	2.38
Botulism	0.04
Encephalitis[a]	0.63
Hepatitis	12.84
Measles (Rubeola)	5.96
Meningococcal infections	1.25
Plague	0.01
Rabies, human	0.00
Salmonellosis, excluding typhoid fever	14.88
Shigellosis	8.41
Typhoid fever	0.23
carriers	0.03
Typhus fever, louse borne	NA
Typhus fever, flea borne	0.04
Whooping cough	0.76

[a] Includes arthropod-borne, enteroviral, and indeterminate etiology encephalites. Arthropod-borne peaks with approximately 70 cases in August in the United States (0.03/100,000).

Source: Centers for Disease Control. "Annual Summary 1980: Reported Morbidity and Mortality in the United States." Morbidity and Mortality Weekly Report 29(54):1-17. September 1981.

reported by CDC, however weekly influenza/pneumonia deaths are recorded. NCHS data provide information on the prevalence of respiratory conditions and diseases and are presented in Table III-2.

A third major communicable disease category is arthropod-borne infections, of which a few are potential problems for the sheltered population or would be initiated during the shelter period to erupt when persons are able to leave the shelter for short periods of time. Epidemic typhus fever is transmitted by the human body louse and the last U.S. outbreak was in 1921. Endemic typhus fever (flea-borne) occurs in the United States (81 cases in 1980), and there would appear to be enough of an infection reservoir to spread endemic typhus fever in places such as Texas. Plague (sylvatic) exists in the western United States, with New Mexico accounting for over one-half of all cases since 1960. Though not expected in large numbers, shelters that harbor rats will create the potential for outbreaks of sylvatic plague. The mortality rate for plague is high, e.g., 5 of 18 cases in 1980. The ability to maintain personal hygiene in the case of louse-borne typhus and rodent control for sylvatic plague will determine the impact of arthropod-related diseases. In this way, the arthropod-borne diseases are similar to enteric infections, which are closely tied to personal hygiene and adequate water supplies. On the other hand, respiratory infections are more closely associated with the level of crowding, ventilation, and state of health of individuals.

Communicable diseases have not reached epidemic proportions following any of the natural disasters in the United States since WW II [48]. Outbreaks have been avoided because sanitary conditions have been maintained. Nuclear war, however, would likely disrupt the normal social and sanitary conditions for large segments of the population. Little medical help will be available, and sheltered populations will not be aided in the short-term by resources brought in from outside. The recent communicable disease experience of industrialized nations probably will not hold during the post-attack shelter period.

(b) Acute and Chronic Conditions

Acute conditions, as defined by NCHS, encompass noncommunicable conditions that may be of shelter significance. Of the estimated 8.5 percent of the sheltered population who would suffer from acute conditions upon entering a shelter, more than half would involve communicable diseases (respiratory and infective diseases). The next largest group would be those recovering and restricted by injuries. A lack of mobility from the injury is not of great concern under shelter conditions, but any infection that may be involved would reduce an individual's resistance to other diseases. A reduced ability to fight infection increases susceptibility to additional infections, such as respiratory problems.

Some digestive conditions require persons to increase water intake due to water loss through diarrhea. Water requirements for persons suffering from enteric diseases and radiation sickness would be higher than levels sufficient for healthy adults, because of changes in the ability to regulate body water levels for enteric diseases and because of damage to mucosal linings of the gastrointestinal tract from radiation exposure.

"Other" acute conditions, as listed in Table III-2, are estimated to be approximately 15 percent of all acute conditions. They constitute a wide range of conditions requiring various levels of medical attention. Most do not constitute a biological threat to the sheltered population. Individuals may be at an increased risk due to unavailable resources and medical attention.

The prevalence of chronic conditions in the noninstitutionalized, civilian population is nearly 15 percent, with two-thirds of those having restrictions in major activities. A number of the conditions, which are defined as chronic, involve physical handicaps that in themselves would have little physiological impact on shelter habitability. However, is known that chronic conditions such as heart disease, hardening of the arteries, diabetes, stomach ulcer, asthma, and thyroid disease increase an individual's intolerance to environmental stresses, e.g., heat and reduced water. Data are not available to more accurately predict the fraction of those with chronic conditions who would be more sensitive to environmental stresses. Under standard shelter conditions, development of respiratory infections is expected to be the major biological stress. Chronic conditions would not greatly change the rate at which respiratory conditions develop. Nearly all shelter occupants will develop a respiratory disease, whether mild or serious, in any case.

Most chronic conditions do not increase susceptibility to radiation damage or to any gastrointestinal disease. The human response to most environmental stresses varies from individual to individual due in part to the state of health, but also because of natural variation. Chronic conditions are not expected to be a major determinant of shelter habitability, but rather the degree of stress to which occupants are subjected is the dominant habitability factor.

(4) Other Considerations

Noise, lighting, circadian rhythm changes, and crowding are well studied environmental stresses. At levels expected in shelters, these should be considered nuisance stresses with the potential for producing minor, reversible physiological and psychological changes in some shelter occupants.

According to one source, any "consideration of the physiological effects of noise on man must of necessity be qualified with a number of uncertainties. This is obviously due to the difficulty in practice of separating what are largely nonspecific stress responses over a period of time into the components caused by noise and those caused by a plethora of other factors" [49]. Other shelter habitability elements could be similarly described.

Noise, lighting, and crowding are not expected to have a significant impact on shelter habitability. Their effects would be psychological and physiologically reversible. Shelter lighting may disrupt daily biological rhythms (circadian) in shelter habitants. Most of the investigations into noise-and light-related physiological or health problems are of long-term chronic exposures to either high noise levels or low-level lighting. Much of the noise work is occupational and oriented toward worker productivity.

Shelter noise levels are not expected to reach levels that cause hearing loss. Chronic exposure to noise levels above 80 dBA can produce hearing loss. Shelters are not expected to reach such levels other than momentarily. Stressful effects of nondeafening noise include sleep interruption, annoyance, hormonal changes, and constriction of peripheral blood vessels [42]. Sounds that cause annoyance, such as sudden, loud, unharmonic, or uncontrollable sounds, may cause constriction of peripheral blood vessels. Human response to noise level changes can also lead to vasodilation of vessels, thought to be a protective reaction to increase hearing sensitivity. This short-lived response occurs at moderate levels of sound, below 70 dBA, where improved hearing sensitivity could be an advantage in protecting oneself from changes in the environment. Vasodilation has been labelled the "Orienting Response," and vasoconstriction is called a "Defense Response" designed to protect one's hearing from prolonged high levels of sound [49].

According to one source, "frequent interruption of sleep or alteration in the normal progression of sleep patterns may be thought to jeopardize physical or mental health eventually" [42]. The relatively short-term shelter period changes in sleep patterns are not expected to be serious. Individuals can acclimate to and control noises that might be found in the shelter.

Noise, combined with crowding and other shelter stresses, could produce behavioral changes. Among the changes that have been described are increased aggressiveness, impaired willingness to help persons in need, and diminished quality of personal interrelationships [42]. None of these potential reactions to noise, though, would be expected to reduce the habitability of shelters. Some noise may actually be beneficial. Extreme quiet could conceivably contribute to uneasiness among shelter occupants.

Emotional distress and changes in circadian rhythm are the light-related shelter responses of concern. The intensity, length, and pattern of shelter lighting may have a physiological impact. A minimal amount of light is required to carry out basic tasks. Two footcandles of illumination is expected to be more than adequate. No adverse health effects of low-level lighting or nonexistent lighting are expected other than possible changes in human circadian rhythms. Occupants may not be comfortable with life in a room that is dark, but lighting is not absolutely necessary to carry out vital functions. Some individuals may have emotional problems with extended darkness. Physiological changes in normal sleep-awake cycles have been given considerable attention.

The types of research that are most likely to be relevant to shelter habitability are studies of light synchronizations of circadian rhythm, human response to continuous darkness, and possibly the circadian rhythm of blind persons. Humans exhibit daily variations in body temperature, respiration, sensitivity to drugs, and other physiological parameters [50]. Light affects these daily cycles. Individuals who shift their time of sleep to a morning to noon cycle in the absence of external cues (daylight, clocks, noise), show the least total sleep time and rapid eye movement (REM) sleep [57]. Blind individuals have shown an absence of circadian rhythms of diuresis and some urinary metabolites, and nonblind persons exposed to 6 days of continuous darkness showed a shift in urinary output of 17 hydrocorticosteroids [52]. This is mentioned to emphasize the point that light does affect certain physiological functions.

What might be expected for shelter occupants is a slight change in length of sleep or length of wake, a phenomenon found among subjects allowed to freerun in an environment with no synchonizing cues [53]. Shelter inhabitants are likely to have wristwatches that would keep occupants on a 24-hour-a-day schedule. There is a circadian rhythm in susceptibility to various toxic agents, due in part to diurnal changes in respiration, cardiac output, and hormonal levels [54]. However, the seriousness of these changes would be minor when compared to psychological stresses of light, noise, or crowding. There is no documentation of serious physiological problems due to short-term altered circadian rhythms. Sleep deprivation increases fatigue and may be of concern. Fatigue affects subsequent sleep quality and ability to perform tasks. Fatigue could be brought on by shelter demands and stresses.

b. <u>Sensitive Population</u>

(1) <u>Thermal Environment</u>

Identified populations that are at greater risk during heat stress include (1) the aged, (2) the young, especially those under 1 year, (3) cardiovascular- and respiratory-diseased individuals, (4) pregnant and lactating women, (5) individuals with body fluid regulatory problems such as diabetes and kidney ailments, (6) persons suffering from febrile illnesses, diarrhea, and other gastrointestinal diseases, and (7) people with major rashes and other skin impairments that reduce sweating efficiency.

Persons over 65 years of age have much higher rates of heat stroke during heat waves [25], although not entirely because of age. Persons over 55 have much higher rates of cardiovascular and respiratory diseases and are more likely to be taking medicines and have reduced lung and cardiac capacities. It is felt that for active individuals over the age of 55, it is not the thermoregulatory system that becomes impaired, but the aerobic power [36]. Therefore, under a sedentary activity level, physically active adults should have similar heat tolerances, regardless of age. In the absence of other (additional) environmental and emotional stresses and given sufficient water supplies, an ET of 82° F has not been shown to be a life-threatening condition for healthy person of all ages.

Humans have the capacity to go without water for up to 2 days. The ability to maintain thermal balance for persons with kidney problems, fevers, and diarrhea is a matter of sufficient body fluids. A temperature of 82° F ET does not, in itself, create problems, but rather fluid lost through sweating and respiration needs to be replaced. When dehydration reaches approximately 5 to 7 percent of the total body water pool, trained athletes begin to have serious problems. For sensitive individuals, life-threatening side effects occur far earlier than a 5 percent dehydration level. Older individuals who experience dehydration require longer periods to return to normal physiological fluid levels [55].

A salt deficit of 0.5 grams per kilogram of body weight causes reduced blood volumes, waterlogged tissues, cramping, and fatigue. Persons with physiological disabilities or chronic medical problems may be particularly vulnerable to water or salt depletion. If salt depletion begins, it is difficult to treat such a steadily deteriorating condition because nausea develops resulting in reduced salt intake, leading to further loss of salt and fluids through vomiting or diarrhea [40].

Heat tolerance data collected by Lofstedt indicate that what is considered light or moderate stress levels (including exercise) for healthy, fit, young individuals may be intolerable for certain individuals [36]. The shelter occupants' ability to minimize temperature and exercise stresses for sensitive individuals and the rationing of available water to the most needy will determine the extent to which heat sensitive individuals will survive.

One of a few experimental studies on water restricted diets for sensitive individuals involved Taiwanese, pregnant women [51]. A water consumption level of 90 percent of normal produced subjective symptoms, but levels down to 70 percent were tolerated for most women for 2 weeks without any apparent irreversible damage. Normal water consumption for these women, who weighed between 90 and 120 pounds, was approximately 3.5 liters daily at 30° C. Assuming this is close to shelter standard temperature and American women require additional fluid intake because of larger body mass, then the 2.5 liters per day which Chow estimated as a minimum requirement to prevent serious complications should be viewed as an absolute minimum for pregnant women in shelters. Three liters of water, and more if available, should be provided. Lactating mothers require additional fluids to maintain mother and child fluid levels.

Drugs that reduce the body's ability to dissipate heat include phenothiazenes (tranquilizers), anticholinergics (nervous system), diuretics (increased urine), and propranolol (cardiac control) [39]. Persons taking amphetamines or lysergic acid diethylamide (LSD) have increased heat production and are predisposed toward heat stroke and hyperthermia.

The nature of temperature stress research has provided physiological and clinical information for temperatures above and below the shelter standard, often in combination with exercise stress (though without fluid or nutritional restrictions). Lack of studies concerning general population response to 82° F ET most likely reflects an absence of serious physiological stress for the normal population, but leaves unknown the response of heat sensitive individuals.

(2) <u>Chemical Environment</u>

(a) <u>Carbon Dioxide</u>

The responses of sensitive populations to increased CO_2 levels has been researched to a small degree. Asthmatic persons with chronic pulmonary insufficiency and emphysema have been studied, but for ethical reasons there is a reluctance to subject humans to levels of CO_2 (and other chemical agents) much above those found naturally.

A few studies have examined human responses to CO_2 at concentrations less than 1 percent, but no adverse responses were found at concentrations of 0.5 percent. In the 0.5 to 1.0 percent range, physiological responses included increased pulmonary ventilation, an increased pulmonary dead space, and increased respiratory acidosis for 21 to 57 days of exposure [58].

For the sensitive population these responses might be expected at the 0.5 percent level, but they alone are not likely to be debililating. The potentially more serious problem is that of the combined effect of CO_2 at 0.5

percent in combination with other shelter stresses for persons with pulmonary or cardiovascular problems. CO_2 will likely be accompanied by other combustion products, such as CO or NO_x, that increase health risks upon exposure.

(b) Carbon Monoxide

CO is a product of combustion and a particularly problematic gas because it quickly acts to deprive body tissues of oxygen. It is a well-studied toxin, though by no means have all the physiological and psychological effects been delineated.

The current EPA CO standard is 9 ppm maximum for an 8-hour average exposure or 35 ppm maximum for a 1-hour exposure [42]. Occupational exposures are required to remain below an 8-hr TWA of 50 ppm [59]. According to one source, the "current EPA standard is mainly justified on the basis of adverse carbon monoxide effects in patients with cardiac and peripheral vascular disease and effects of carbon monoxide on oxygenation of skeletal muscles in exercising normal human subjects. There appears to be an adequate safety factor between the lowest carboxyhemoglobin (COHb) concentration that has been demonstrated to cause adverse effects and the maximal COHb concentration that can occur at 9 ppm CO for 8 hours or 35 ppm for 1 hour" [60].

Two effects of carbon monoxide are (1) competition with oxygen for red blood cell (hemoglobin) bonding sites and (2) increased oxygen affinity for hemoglobin, reducing the amount of oxygen that gets absorbed by body tissues [42]. For the healthy person, exposure to low concentrations of CO (50 ppm) likely produces insignificant changes in oxygen use and body functions. Persons with angina pectoris, however, have shown a decrease in mean exercise time before onset of pain at 50 and 100 ppm CO [42]. Inhalation of CO increases cardiac pressures (left ventricular) and COHb content of all blood--coronary, arterial and venous [61]. Persons with chronic obstructive lung disease are another group who could be sensitive to CO exposure especially during exercise. Dyspnea (limited or labored breathing) is brought on more quickly in such persons under exposure to 100 ppm of carbon monoxide when exercising [61].

The additional factor of elevation above sea level that reduces oxygen delivery to body tissues would aggravate oxygen related CO problems. Above 5,000 feet oxygen partial pressures are lowered enough to reduce oxygen transfer capacity of the blood tissue barriers and CO reduces it further. However, the numbers of nonacclimated individuals being placed in high altitude shelters would be restricted to the Rocky Mountain, Cascade, and Sierra mountain ranges estimated to be less than 3 percent of the U.S. population.

(c) Nitrogen Oxides

According to one source, "Many of the adverse effects reported in the past for CO alone may be related to the combined action of COHb and methemoglobin (caused by nitric oxide) especially inasmuch as sources that emit carbon monoxide often produce nitric oxide as well" [42]. The most notable of such sources is combustion. A nitric oxide (NO) level of 3 ppm appears to be comparable with carbon monoxide at 10 to 15 ppm [42].

A community air environmental standard for nitrogen dioxide (NO_2) is 0.05 ppm. At levels slightly above 0.05 ppm, which can be produced by gas cooking, human responses include changed sensory perception and eye irritation. At 0.12 ppm, NO_2 can be smelled [62]. Asthmatics show increased bronchoconstriction at levels of 0.1 to 0.2 ppm NO_2, and at 0.5 ppm, asthmatics and persons with bronchitis, when exposed for 2 hours, complained of lightness in the chest, eye irritation, headache, or dyspnea [63]. In the same group, pulmonary function changes were significant and discharges from the nasal cavity increased.

Most epidemiologic studies involve the combined effects of NO_x and other pollutants. However, observed excesses in acute respiratory disease have not been attributed to NO_2 at a concentration of 0.3 ppm [42]. For the length of time persons are exposed under shelter conditions, no significant increase in acute respiratory diseases is expected due to NO_2 alone at concentrations below the 1-ppm level.

(d) Smoke

While tobacco smoke affects both the smoker and the nonsmoker (involuntary, passive, or sidestream smoke), combustion products from external fires are of far greater concern. Shelter occupants would have far less control of external pollutant souces (e.g., fires) than internal sources (e.g., smokers, gas stoves, or lanterns). Physiologically and emotionally stressed individuals will not suffer acutely from tobacco-related contaminants. Hence, the following discussions will focus on combustion products from fires, lighting, and heating.

In a fire, combustion products are a mixture of gases and particulates and will probably be toxic: "Evidence indicates that the total toxicity is greater than the sum of the toxicity of the components of the mixture" [64]. Sulfur dioxide, hydrogen chloride, formaldehyde, formic acid, carbolic acid, aldehydes, ammonia, and cyanide are a few of the combustion products produced when wood or plastics are burned. CO, CO_2, and NO_x are likely to be formed in large quantities. Due to the number of combustion products, there will be no attempt to catalogue all the responses to individual pollutants.

Sulfur oxides have been implicated in acute air pollution episodes as a major cause of increased mortality among persons with chronic lung disease [65]. However, other pollutants existed in such places as London and Donora, Pennsylvania, where such episodes took place. Sulfur oxides may be present in shelter areas due to burning of rubber products, and as in pollution episodes, will be mixed with other products of combustion.

Standard shelter conditions attempt to create a survivable environment so that air pollution episodes should represent the worst case for shelter conditions. Exposure to the highly noxious and toxic conditions experienced by fire fighters and occupants of burning buildings will be considered as nonstandard conditions.

The young, especially infants, older persons, and persons with pulmonary diseases or irritation, are especially susceptible to low levels of combustion products, as mimicked by air pollution episodes. Morbidity rates for lower chest infections are shown to increase in populations experiencing moderate pollution (0.06 ppm of SO_2) versus low pollution regions (< 0.03 ppm SO_2) [65]. This suggests that lung infections might develop among shelter inhabitants, especially the young, and in concert with other shelter stresses could add to the general morbidity of sensitive populations. There will be discomfort for shelter occupants exposed to smoke. Among the sensitive population there could be increased mortality, but relative to other stresses at standard conditions it will likely be a small factor in shelter habitability.

(3) Biological Environment

A discussion of the expected biological response to the shelter environment is meaningful in qualitative terms. There exists little modern experience from which to draw an accurate picture of shelter occupancy on a national scale. What follows is a general discussion of those persons who could be expected to develop serious infections or conditions due to biological agents.

Respiratory infections having been identified as the major communicable disease of the shelter period are known to more seriously affect certain population groups. Among these groups are:

- Persons who have recently suffered from major respiratory infections
- Person with pulmonary insufficiencies
- Persons whose immune response system is functionally reduced
- The young and old
- Possibly, those who live in polluted environments.

Respiratory infections spread more rapidly and become more severe in persons with lowered resistance (immune response deficiency). For those with lowered lung function (young, old, and persons with lung tissue damage or scarring), infections tax the lungs and other body functions to a greater extent.

Gastrointestinal problems could develop in many persons who, though otherwise healthy, have not previously been exposed to enteric pathogens and have, therefore, no immunity. Depending upon the agent, immunity is built up in those who have been exposed to pathogens. Conditions such as ulceration and gastrointestinal changes due to disease, medication, and diet predispose individuals toward adverse gastrointestinal reactions. Again, those persons whose immune response system is weakened, will be at greater risk when unsanitary conditions exist. Young and old people more commonly have less effective immune response systems and are, therefore, more vulnerable to gastrointestinal attacks. Diseases transmitted by insect vectors similarly affect more seriously those strong persons with no previous exposure, with weakened states of health, or with reduced immune functions.

A large segment of the U.S. population suffers from allergic reactions to airborne biological agents. Those allergens would not be expected at greater than background levels in the shelter, even in highly confined spaces. Few airborne allergens are found in enclosed spaces and most have natural sources. Depending upon season and local weather, pollens, fungi, and other allergens could exist in the shelter when entered. Once the population is in place and ventilation is kept to a minimum, few biological allergens would be expected. Adverse allergic reactions would be expected in extremely small numbers.

(4) Other Considerations

Those individuals who may be more sensitive to noise, low illumination levels, and crowding are persons with certain emotional instabilities and persons with special daily patterns and needs. Many elderly persons sleep less and sleep at different hours than the young and adult populations. Noise and lighting could contribute to difficulties in maintaining sleep/wake patterns, causing psychological and physiological stress.

The very young could be traumatized by unknown noise and lack of lighting. These two groups, the very young and old, could be accommodated with little or no additional stress being placed on other shelter occupants.

Emotionally disturbed individuals may be controllable depending upon the severity of their instability. All occupants will be traumatized to some extent because of the abnormal conditions they would be placed in. Under standard shelter conditions there may be individuals who should be sedated.

Some disturbed individuals can be calmed and controlled through group actions. Males typically show more signs of aggressiveness than females due to crowding and other psychological stresses, whereas women often become more passive and accommodating [54,66].

To reduce the impact of these potential shelter stresses, individuals can be informed of expected shelter conditions and they can be provided basic instructions on how shelters can be organized and controlled so as to reduce psycho-physiological reactions.

3. Responses to NonStandard Conditions

a. Normal Population

(1) Thermal Environment

(a) Heat

Effective temperatures up to the low 80s (°F) are for the most part studied because of human comfort. Above an 82° F ET, the problem switches from one of comfort to one of physiological stress. Factors that determine heat tolerance, i.e., acclimatization, level of work being performed, intake of fluid, and cardiovascular fitness, all become increasingly important as humans are exposed to temperatures into the 90s and above.

Nonstandard thermal conditions could be defined as temperatures above 82° F ET or below 50° F and accompanied by any combination of work levels above 80 to 105 watts (resting level), fluid intake below 1 gallon per day, salt intake less than 15 grams daily, and rations less than 1,500 to 1,800 calories daily.

In a study for the Swedish Civil Defense Administration, Burse and Goldman estimate the maximum temperature that should be allowed for men and women for several work loads (30 minutes of work, 30 minutes of rest) [67]. At a work load 50 percent above resting, women could tolerate mid 90° F temperature for a 4-hour period. At work levels 100 percent and 150 percent above resting, temperature would need to be below 88° F and 85° F ET, respectively. These standards are based upon predicted rectal temperatures and heart rates.

Incidences of extreme overcrowding have been studied and are useful in understanding potential problems of nonstandard shelter conditions [68]. The multivariate stresses of such events are more likely to reflect shelter conditions than scientific research which places subjects in highly controlled environments. No thorough analysis has been made of extreme overcrowding to separate out the various physiological, environmental, and behavioral components. The morale of crowded and sheltered persons often may make the difference between life and death. For example, slaves being transported from Africa were reduced to apathy and despair and suffered high losses. (They also suffered from restricted water and food intake and temperatures between 120° F and 130° F.) On the other hand, european Jews following World War II tolerated very crowded conditions below deck in ships, in part, because of the hope and enthusiam for new lives. Following nuclear attack, sheltered populations could be expected to have morale problems.

The studies of heat-wave hospitalizations and deaths are also useful, but of slightly limited value in predicting shelter habitability. Shelter temperatures would be expected to remain much more constant than the diurnal variations in urban dwellings. Shelter occupants would likely have greater fluid restrictions, would likely be less active, and would be suffering greater psychological stress than heat wave sufferers. Nonetheless, effective temperatures above 82° F ET will create problems for the unacclimatized population. When individuals are not able to maintain body temperatures below 100° F, physiological and psychological impairments occur. Resistance to disease is reduced and mortality may increase due to thermal stress. It has been shown that high humidity and high temperatures correspond to higher death rates for persons suffering from pneumonia for more than one week [69]. In general though, death rates are negatively correlated with humidity and temperature [69]. In a heat wave the actual number of individuals constantly exposed to extreme temperatures depends upon the number of persons working or residing in nonair-conditioned environments. The morbidity and mortality rates experienced by the elderly poor more closely resemble the expected heat stress response of sheltered populations because the elderly poor are not typically protected from the heat. During the July 1980 heat wave, St. Louis and Kansas City's lowest socioeconomic groups suffered heat stroke rates of 5.58 and 3.65 per 10,000 (age adjusted), respectively [25]. Those over 65 suffered at rates between 10 and 12 per 10,000.

In a physiologic sense, the heat balance equation requires that the amount of body heat being generated internally equals the amount of heat lost through evaporation and radiation, convection, and conduction:

$$M = H + E,$$

where

M = metabolic heat production

H = combined heat lost through radiation, convection, and conduction

E = heat lost by evaporation (includes sweating and respiration).

Man's basal heat production is approximately 70 Kcal/hr (80 watts) and is raised with physical activity. Heavy muscular activity as experienced in occupational settings can raise heat production to 600 Kcal/hr. When ambient temperatures are higher than skin temperature, then one no longer removes body heat via H but rather gains heat. Evaporation therefore becomes all the more important to thermoregulation as temperatures climb into the 90s. The water lost in evaporation must be replaced. One can crudely estimate the water needs of inactive shelter occupants during heat stress using the latent heat of vaporization of 0.7 watt-hrs/gram. At the basal metabolic rate of 80 watts, the equivalent amount of water lost per hour is 0.115 liters. One loses more water under humid conditions where complete evaporation of sweat does not occur. The need for water grows as ambient temperatures (and ETs) rise. If an average body has an excess of 140 watts that is not dissipated, a core temperature of approximately 39.2° C (102° F) results, with a 25 percent risk of heat exhaustion collapse [70]. At 185 extra watts, the core temperature is 39.5°C (103°F) with a 50 percent risk of collapse, and at 280 watts temperatures will go above 104° and almost no one will be functional [70].

The prevention of heat disorders among sheltered populations when effective temperatures are above 82° F ET is largely determined by the degree of acclimation, the availability of potable water, the level of activity required, and adequate ventilation to aid heat dissipation.

(b) <u>Cold</u>

Cold stress is a potential problem in the northern United States during the colder months of the year. Shelters there that are not fully occupied may not have enough body heat generated to bring temperatures up to within a range of the standards (50° F db to 82° F ET). Temperatures between 68° F and 75° F are in the comfort range for a majority of Americans [20]. It is temperatures below 65° that present problems for some groups, such as the elderly, who are more susceptible to hypothermia.

The immediate physiological responses to cold are (1) constriction of blood vessels of the skin to reduce heat loss (reducing heat delivery to extremities to one-tenth) [71], (2) shivering to produce heat, and (3) reduction of surface area by body flexion. If cold exposure continues, nonshivering thermogenesis is used to generate heat. Nonshivering thermogenesis is improved with cold acclimation and it appears to involve the sympathetic nervous system and norepinephrine [72].

When core temperatures fall below 95° F mental abilities deteriorate, and below 90° F unconsciousness occurs, with cardiac irregularities beginning around 85° F. Death is almost a certainity when body temperatures fall below 80° F. Physiological changes observed in hypothermia include increased blood sugar, decreased blood flow, increased blood viscosity, and cardiac impulse changes [73].

Acclimatization is a response to constant cold exposure, but persons living in cold climates are not necessarily acclimatized [20]. Persons who work outdoors in cold climates become acclimatized. Features of cold acclimatization are increased heat production, increased heat conservation, increased tolerance of cold effects, and improved sensitivity of heat regulating mechanisms.

Cases of hypothermia are not restricted to the colder environments, but are even reported in places with high average temperatures [73]. A number of factors are related to hypothermia, (1) old age, (2) exhaustion and exposure in mountain hiking and water immersion, (3) alcohol, (4) barbituates, phenothiazines, and amphetamines, (5) CO and other poisons, (6) infancy, and (7) disease. [71,73].

Some older people experience changes in metabolism and thermoregulation which affect response to cold stress. Those who are at the greatest risk are not able to shiver, a response which can bring about a five-fold increase in metabolic heat production [72]. Contributing to the increased risk of older persons are poor peripheral vasoconstriction, less consciousness of the cold, severe undernutrition, lack of subcutaneous fat, anemia, and hypoglycemia [73].

Cold stress is also associated with cardiovascular mortality and limb injury such as frostbite and tenderfoot. The association between cold weather and ischemic heart disease has been studied and it appears that the amount of snowfall or snow mixed with rain is partly to blame for sudden death during cold weather [74,75]. The physical exertion of snow removal plus cold stress shows itself in sudden deaths in the under-65 male population [75].

Prevention of cold stress is more easily done than prevention of heat stress. Clothing is the first line of defense. The insulation value of clothing, blankets, and other wrapping materials allows adequate heat retention by the body. Another protection strategy would be the creation of small living spaces to conserve heat. A few persons who might find themselves in a large shelter should attempt to close off large portions of a cold shelter. Food intake, though of lesser importance, will help individuals maintain metabolic heat production, especially persons with little body reserve. Physical activity will help generate heat, but will also require some food intake and adequate water. Unless adequate clothing, bedding, and makeshift insulation materials are not available, sheltered populations should have little trouble coping with low temperatures.

(2) Chemical Environment

Nonstandard conditions would be expected where inadequate ventilation occurs or where hazardous substances originating outside the shelter cannot be kept out of the shelter. Filtering of outside air would likely not control noxious gases such as CO_2, CO, NO_x, or SO_2. Exposure to these gases at levels above those discussed as standard conditions can be life threatening.

(a) Carbon Dioxide

Acute exposure to high carbon dioxide concentrations has immediate and significant effects on the central nervous system. At 20 to 30 percent carbon dioxide, unconsciousness and convulsions occur in less than 1 minute. Abnormal EEGs (brain wave measurements) and cardiac irritability were also reported for 30 percent CO_2 [58]. At concentrations between 11 to 13 percent, it takes longer--8 to 23 minutes of exposure--to produce neurological changes, including unconsciousness. A concentration of 7.5 percent CO_2 produced headaches, restlessness, and dizziness after 7 to 15 minutes of exposure [58]. Physiologically, CO_2 increases cerebral blood flow and cerebrospinal fluid pressure, causing headaches.

One effect of increased carbon dioxide levels is increased respiratory volume and rate. A concentration of 5.2 percent CO_2 with heavy exercise caused a 16-fold increase in volume of expired air [58]. The following shows the relationship between CO_2 and respiratory volume at rest:

CO_2 Concentration (%)	Respiratory Volume (ℓ/m)
0.03	7
1.00	8
2.00	9
3.00	11
5.00	26
10.40	76.8

A dramatic increase is respiratory volume appears to begin around 3 percent.

Cardiovascular changes are also reported, with older individuals being more sensitive. Decreased amplitudes of the QRS electrical waves as measured by ECGs were found in 6 to 8 minutes of exposure to 6 percent CO_2 [58]. "The majority of cardiac effects have been observed at high concentration of both oxygen and carbon dioxide" [58] which would not occur under shelter conditions. It is not clear what the cardiovascular response would be to carbon dioxide alone.

CO_2 exposure affects body acid-base balance and produces electrolyte changes. This, in itself, is unlikely to cause significant morbidity or mortality for the relatively healthy population. The human body will slowly compensate for respiratory acidosis at the 1.5 percent CO_2 level and small drops in blood pH are not correlated with any clinical symptoms.

Acclimatization to increased carbon dioxide partial pressure has been shown in a number of studies. Respiratory efficiency increases where oxygen uptake and carbon dioxide excretion is improved. For CO_2 levels below 3 percent, the healthy individual would likely not be adversely affected given all other chemical hazards are at safe levels.

The combination of CO_2 and exercise stresses (180 W) has been shown to have a synergistic effect on physically fit individuals [58]. The greater the exertion the more pronounced are the effects. Above 2.8 percent CO_2, muscle pain, respiratory difficulty, and mild headaches have been reported. At 5.2 percent CO_2, strenuous exercise resulted in mental confusion, impaired vision, and collapse.

It is, therefore, envisioned that for moderately fit shelter populations carbon dioxide levels below 3 percent could be tolerated for extended periods in the absence of other stressors such as additional combustion products. Heavy exercise would add significant stress to persons exposed to CO_2 above 0.5 percent, the shelter standard.

(b) Carbon Monoxide

Acute exposure to carbon monoxide quickly increases carboxyhemoglobin saturation, because of the preferential affinity of hemoglobin for CO. Exposure to greater than 500 ppm CO for over an hour will lead to approximately 20 percent COHb saturation. Exposure to 1,500 ppm for 1 hour can be fatal.

Valuable information has been developed from the study of fire victims. A COHb level of 65 percent is nearly always lethal [76]. For COHb between 50 and 65 percent, death has been known to occur. Though carbon monoxide exposure is important in fire related casualties, there is also considerable exposure to smoke and other noxious gases. This may well reflect the situation to be encountered in many shelters where urban fires threaten shelter habitability.

A time-concentration equation has been developed for CO exposure that appears useful in estimating shelter problems [77]. The equation is:

$$
\begin{aligned}
\text{Hours x ppm} &= 300 \text{ (no perceptible effect)} \\
&= 600 \text{ (just perceptible effect)} \\
&= 900 \text{ (headache and nausea)} \\
&= 1{,}500 \text{ (dangerous to life).}
\end{aligned}
$$

In situations where persons are exposed to a number of combustion products, CO is usually the first to reach dangerous levels [78]. The possible synergistic or additive effects of carbon monoxide should be of great concern as regards shelter habitability, but is an area that is only beginning to be understood. The length of time that fires could continue following an attack and the length of time that persons would be occupying shelters together may create a potentially hazardous situation.

(c) Nitrogen Oxides

The effects of high nitrogen dioxide concentrations for short periods can be summarized as follows [79]:

NO_2(ppm)	Clinical Effect	Time Between Exposure and Termination of Effect
500	Acute pulmonary edema--fatal	<48 hrs
300	Bronchopneumonia--fatal	2 to 10 days
150	Bronchioites fibrosa obliterans--fatal	3 to 5 wks
50	Bronchiolitis, focal pneumonitis--recovery	6 to 8 wks
25	Bronchitis, pneumonia--recovery	6 to 8 wks

Mathews has provided the following summary of human toxicological information for NO and NO_2 [80]:

Compound	LC_{50}[a]		TLV[b]	EPL[c]
	5 min	30 min		
NO	410	250	25	0.04
NO_2	--	--	5	0.05

[a]Lethal concentration--fatal for 50 percent of those exposed
[b]Threshold limit value--occupational exposure
[c]Estimated permissable limit--to reduce exposure to levels where no physiological response is recorded.

Other human responses that would be expected at elevated NO_2 levels include increased airway resistance (concentrations between 0.7 and 40 ppm and exposure times ranging from 5 to 45 minutes). Airway resistance has been shown in a number of studies involving both health and chronic respiratory-diseased individuals [42]. The initial and major problems will be respiratory related for the normal population at moderately elevated NO_x levels.

(d) Smoke

Combustion products at levels above that found in ambient air could be a real shelter hazard. A number of potential combustion products, in addition to those mentioned above, are highly toxic substances, e.g., hydrogen cyanide and sulfur oxides. A combination of these products could be expected to have synergistic properties similar to those observed in air pollution. It has been stated that single pollutants don't explain the potential health risk of urban atmospheres [81]. It should suffice to say that smoke is a serious hazard and is potentially a life threatening condition to be avoided, if at all possible, during post-attack shelter occupancy.

(3) Biological Environment

Shelter conditions that affect the ability of sheltered populations to maintain health include (1) crowding, (2) disposal of wastes, (3) water for hygienic purposes, (4) radiation exposure, and (5), to a lesser extent, nutrition and thermal-chemical stresses. Each one alone increases the potential or seriousness of the infections and diseases that could develop. In combination, they would be expected to act, as a minimum, in an additive fashion. All of the above mentioned factors influence the development of infections because they either increase the number of organisms initially contacting the body, add infectious agents to an already infected person, or they reduce the body's defense mechanisms.

Crowding increases the chances of pathogens being passed from one person to another. Under standard shelter conditions there will be a rapid spread of respiratory infections. Any reasonable reduction in square or cubic footage per person will not change the expected respiratory infection rate since nearly 100 percent of the population would be expected to develop respiratory conditions either mild or serious. Crowding causes emotional stress which also contributes to the development of more serious respiratory and gastrointestial infections. Psychological stresses can sometimes be reduced through group actions. Shelter conditions will determine to what extent psychological stresses can be controlled given all the environmental stress situations.

Sanitation and personal hygiene are highly dependent on the availability of water, cleansers, and waste disposal equipment. Shelters are not routinely equipped with adequate water for all purposes and water for drinking purposes takes highest priority. The expected spread of enteric diseases will be difficult to control where water is in short supply. Children are particularly vulnerable to contacting and spreading diseases associated with poor hygienic practices. Non-standard sanitary conditions could be considered as those situations where (1) water and/or cleaning solutions are in very short supply, (2) well-sealed disposal equipment is not available, and (3) there is little control of individuals hygienic practices.

Shelter conditions would be far from ideal and once the population is in place there is little that could be done to improve the conditions. Short excursions out of the shelter may be possible after some days depending on radiation levels. The exposure of individuals to radiation above that experienced in the shelter compounds the radiation-induced health problems. If the cumulative dose for an individual remains below 100 rads, acute affects are kept to a minimum. The delayed response of radiation sickness will be felt a few days after exposure with symptoms of anorexia, nausea, and diarrhea. It will be difficult for shelterees to know what the exposure levels are outside the shelter without detection equipment. The caution required of shelter occupants will be weighed against the need and desire to obtain water, food, and medicines.

Insect and rodent vectors could be a real concern during the shelter period. A prolonged shelter stay could increase the chances that rodent vectors will become a problem. The shelter period will contribute to post-shelter communicable disease problems. Insect populations will recover and would become a public health problem following the initial 2- to 4-week shelter stay.

An important determinant of health for the sheltered is the combined or synergistic effect of more than one environmental stress. It appears that the stresses work synergistically [46,82]. Reduced resistance due to radiation, increased transmission of disease, and reduced medical resources together create a serious health problem. Add to these the potential thermal and chemical stress and one is faced with very serious problems of life and death.

(4) Other Considerations

Unless a sheltered population is exposed to high-pitched sounds above 90 decibels for longer than 2 weeks, there would be little chance of individuals developing permanent hearing loss. Some individuals could develop tinitus (ringing in the ears) from steady high pitched, high volume sounds, a condition that also may have a strong psychological input. The physiological impact of loud noises is often compounded by psychological reactions, and the two are difficult to separate.

Loud, uncontrolled noises can cause disruption of sleep, decreased communication, and increased aggressiveness. Such responses could jeopardize shelter mental health. When enough sleep is lost, fatigue develops that reduces resistance to physical and biological agents. Noise stress of this magnitude or duration is not expected. If it is the case that loud noise persists in the shelter, it is likely that urban fires and winds are not being completely dampened by the shelter structure. In such a case, noise is not likely to be the major element of shelter habitability.

Lighting is not absolutely necessary for shelter functions. As has already been discussed most shelter needs can be taken care of without lighting. A completely dark shelter would create additional problems in maintaining sanitation and orderliness. Lack of lighting would add to the overall psychological stress of a sheltered population.

Circadian rhythms could be altered under extremely low illumination levels. Light has been shown to be important in synchonizing 24-hour days and diurnal changes, but given social interactions of shelter life, there needs be little concern for the normal population [83]. Profound changes in circadian rhythms are not expected.

b. Sensitive Population

(1) Thermal Environment

A discussion of sensitive populations to cold stress is presented in III.B.3.a and will not be reiterated here, though many of the same population groups are sensitive to both heat and cold stress. Old age, infancy, cardiovascular diseases, respiratory diseases, pregnancy and lactation, diabetes, kidney ailments, rashes, gastrointestinal diseases, and strenuous exercise increase the risk that a hot environment will cause serious physiological problems [25,31,39]. Unacclimatized humans tolerate heat stress poorly. The legal and ethical difficulties in studying sensitive population groups under controlled heat stresses leaves only the epidemiologic literature as a major source of information.

Physical changes in the integrity of the skin and pores causes increased risks during heat exposure. Two controlled experiments involved heat-acclimatized individuals who were wrapped for 3 days in plastic to develop miliaria rubra (heat rash) [84,85]. After 7 and 14 days following unwrapping, most subjects were still unable to complete 100-minute treadmill walks. At day 7, the test group had 2.5 times the body heat storage of a control group, and at 14 days the body heat storage was 1.5 times the control, even though the rashes were not clinically detected [84]. Heat intolerance due to rash does not appear to be resolved until after 21 days. As a percent of body surface area, the torso, neck, and head are able to sweat more than arms or legs and, therefore, are more critical to thermoregulation [85].

Heat-wave-related morbidity and mortality statistics draw the association between population characteristics and disease and health rates but do not develop any cause and effect relationship. Incidences of heat-wave-related deaths are by no means a recent phenomenon. Armies and athletes have suffered losses due to heatstroke going back more than 2,000 years [39]. The hot conditions experienced by sheltered populations, will likely be humid. People will be sedentary. Athletes and military recruits are not typical of sensitive shelter populations, so literature that compares population characteristics with morbidity and mortality rates is not particularly relevant.

It is not the healthy, sedentary adult who shows up in hospitals during heat waves. Temperatures of 100° F or more (ETs greater than 85°) are associated with excess heatstroke among unacclimatized populations [25]. No mathematical relationship has been developed that relates morbidity or mortality to ETs (or any other scale). Thus, we can only talk in generalities. Two weeks of average effective temperatures above 85° F will be stressful. Water needs increase with temperature, and physical exertion needs to be kept to a minimum for all sensitive groups under hot temperatures.

The rates of heat-wave mortality for given population segments are likely to be low by an order of magnitude when compared to that expected in shelters because modern populations protect themselves with air conditioning and rarely have fluid restrictions. If temperatures climb into the 90° F ET range and if any ventilation or fluid restriction develops in a shelter, then there is a good possibility that deaths will occur. Any action to reduce the temperature exposure, to provide potable water, and to improve ventilation will improve the chances that sensitive populations survive.

(2) Chemical Environment

The young, the old, and persons with various cardiovascular conditions or diseases are most sensitive to chemical stressors. CO_2 directly affects the ability of the lungs to exchange oxygen across parenchymal tissues (alveoli). Persons with respiratory problems, such as asthmatics and emphysematics, and persons with chronic respiratory obstruction are sensitive to high levels of CO_2 (more than 2 percent), though very few experimental human data have been developed showing an increased sensitivity. However, due to physiological responses at low levels (less than 2 percent) it is likely that sensitive persons may be seriously affected if CO_2 levels reach 3 or 4 percent. Persons with cardiac abnormalities would have increased sensitivity at these levels, as opposed to healthy individuals who may be able to acclimate.

CO adversely affects a number of population groups, including children, older individuals, cardiovascular-diseased persons, and persons with chronic obstructive lung disease. Smokers may also be more susceptible to CO poisoning since their background COHb levels are likely to be higher than those of nonsmokers.

Whereas a healthy, nonsmoking person may be able to tolerate COHb levels of up to 50 percent for short periods, the combiration of 20+ percent COHb and cardiovascular disease has been implicated in a number of fire-related deaths [76]. An increased severity of coronary vascular disease allows for reduced COHb levels to bring on death. Exercise and heat stress compound cardiovascular problems and would be expected to put persons with cardiovascular disease at a greater risk with elevated levels of carbon monoxide and other chemical stresses as well.

Likewise, NO_x is particularly stressful to persons with respiratory problems. In addition to pulmonary function effects, increased susceptibility to respiratory infections has been shown for humans exposed to NO_x.

It is highly unlikely that any one chemical hazard will exist in the absence of other chemical or environmental stressors. The literature on fire and air pollution hazards is therefore valuable in understanding chemical risks to shelter inhabitants.

In work for the Office of Civil Defense, the Southwest Research Institute performed experiments exposing white mice to combustion products singly and in combination [86,87]. These experiments identified four primary variables (CO, hyperthermia, anoxia, and CO_2), five noxious gases (SO_2, HCN, NO, hydrogen chloride, phosgene), and smoke as fire-related test parameters. It was found that the primary variables acted in an additive way, though CO_2 was additive in some cases and antagonistic in others. The noxious gases--NO_2, HCN, and SO_2--in combination with the primary variables produced synergistic responses in the test animals. In tests involving combustion products from burning materials, such as Douglas-fir, wool, and vinyl-asbestos floor tile, synthetic materials were found to be more harmful than combustion of wood and wool. Smoke and noxious gases from the burning materials were indicated as toxins. Hydrogen chloride proved to be very toxic. These tests indicate the presence of toxic elements, other than CO, CO_2, and heat, and suggest that their presence is important in determining toxicity.

Children seem to have increased sensitivity to high air pollution levels, due in part to higher ventilatory rates per body weight. Cardiovascular diseases and respiratory diseases and insufficiencies predispose individuals to greater risks when they are exposed to chemical stressors such as combustion products. The data base does not exist to develop a dose-response relationship for sensitive persons versus a healthy population, but any dose response curve would be shifted to the left for sensitive individuals.

(3) Biological Environment

The potential for major outbreaks of communicable diseases and the life-threatening situation where medical supplies are limited or not available for acute and chronic conditions are real problems that would affect sheltered populations. Sensitive populations would be expected to show higher morbidity and mortality under both standard and nonstandard shelter conditions. As the biological and combined biological-thermal-chemical stresses become more severe, the distinction between sensitive and normal populations would be diminished.

Considering communicable diseases, the identified populations, even under standard conditions, will be at risk of developing serious infections. Additional stress due to radiation or other thermal and chemical conditions would create high mortality rates for the sensitive individuals. Any discussion of the expected response to the biological environment must necessarily be qualitative. Estimates have varied widely for communicable disease morbidity and mortality rates expected following nuclear attack, reflecting unknowns of shelter conditions, extent of urban, industrial, and military destruction, communicable disease rates, and social disruption.

An additional factor not previously discussed for sensitive populations is exposure to radiation. Persons whose immune response system, respiratory tract, and gastrointestinal systems are damaged or diseased are particularly vulnerable to radiation. A radiation dose, say 100 rads, that causes moderate reactions in many individuals would contribute to increased mortality within a few months among the sensitive individuals [88]. Radiation itself may not cause mortality, but it reduces or destroys the bodies ability to fight infection. Increased mortality due to infection would be expected.

Sensitive individuals are not always easily identified. Those with most acute conditions would be at increased risk, but persons with immune response deficiencies or persons with radiation hypersensitivity may not always be self evident. There is no expected difference in type or response for sensitive individuals other than the response would be precipitated at lower exposure levels or sooner. The dividing line between normal and sensitive populations is not easily drawn because, in terms of health, there is a spectrum of sensitivity among the population whether one is talking about radiation, immune response, or communicable disease. Certain communicable diseases show a dichotomous response where the disease manifests itself with well-identified symptoms. Other communicable diseases show a spectrum of responses depending upon challenge dose and an individual's state of health and immunity. Except when radiation doses exceed 500 rads, when ETs go above 100° F, and when combustion products are uncontrolled, a spectrum of responses would be expected. Those defined as sensitive will increase proportionally as environmental conditions become more severe.

(4) Other Considerations

Persons with certain psychological conditions or tendencies may be adversely affected by extremes of noise, lighting, or crowding. Physiologically, hormonal imbalances could affect persons under adverse shelter conditions by reducing sleep or altering dirunal rhythms. The psychological stress of a nonstandard shelter environment, including atypical noise and lighting levels, may produce extreme behavioral manifestations that would be uncontrollable without drugs.

There is very little light or noise research to describe the reaction that could be expected of shelter occupants over the 2 week stay. It is difficult to define or possibly screen for individuals who are particularly sensitive to loud or constant noise or for individuals for whom complete or nearly constant darkness would be debilitating. If darkness prevents basic needs from being met such as administering essential drugs, life threatening situations could occur. It is not expected that all individuals will react to such an abnormal situation as shelter occupancy with calmness and self control. The absence of light or exposure to annoying or deafening sounds would add to occupant stress. With virtually no comparable disaster literature or controlled experiment to call upon, it is difficult to define sensitive populations or to define the nature and extent of these stresses.

C. Occupant Responses (Psychological)

This section is a summary of the status of shelter habitability research as it applies to the psychological environment likely to be found in shelter occupancy. The following discussion is organized around four major questions intended to address the issues of importance:

- What research approaches have been used?
- What psychological factors of importance are indicated by the research?
- What is the likely impact of these psychological factors?
- What recommendations do the research suggest?

Each of these questions is addressed by one of the following four subsections.

1. <u>Research Approaches Used</u>

While research regarding physiological aspects of shelter occupancy can be reasonably straightforward, research regarding psychological effects has been severely constrained by problems with simulating the psychological environment. While the physical dimensions of the environment of interest can be easily duplicated, psychological factors (e.g., fear of imminent danger, a sense of alienation and loss) cannot easily be duplicated within the bounds of ethical considerations. This fact has had a profound effect upon the nature of related psychological research and upon the interpretations that reasonably can be placed upon the research findings.

Research reported in the literature regarding psychological effects of shelter confinement can be broadly categorized as research based upon:

- Actual shelter occupancy experience
- Experience in other settings thought to be somewhat representative of the total psychological shelter environment
- Situations limited to a representation of one or several of the psychological factors expected to be encountered during crisis shelter occupancy.

While a review of the literature on psychological effects of shelter occupancy indicates that the actual shelter setting has only minimally presented a realistic psychological environment, a number of useful studies have been conducted in actual shelters or in settings that are physically similar to actual shelters. Such research has been conducted both to identify the psychological factors of interest and to provide limited cause and effect data related to the combined or total impact of these factors.

A study by Vernon [89] represents a first attempt to determine (1) whether or not a family could remain confined in a shelter for a period of 14 days and (2) the nature and gravity of any problems associated with shelter occupancy. Because of the exploratory nature of the study, no hypotheses were stated. The study procedure was simply to place the subjects in the shelter and observe the results. The study was successful in that it clearly indicated that a particular five-member family was capable of easily withstanding 14 days of confinement in a simulated fallout shelter and that the problems encountered were so minor as to preclude any but the most general of conclusions regarding psycho-social stresses.

The Vernon study was followed, in the 1960s, by a number of exploratory shelter studies intended to build upon the Vernon study. Examples of these are studies by Altman, Smith, Meyers, McKenna, and Bryson [90]; Goldbeck and Newman [91]; Strope, Schultze, and Pond [92]; Ramskill and Bogardus [93]; Strope, Etter, Schultz, and Pond [94]; Hammes and Osborne [95]; Hammes [96]; and Hale, Rosenfeld, and Berkowitz [97]. While the primary emphasis of these studies was on physical conditions in shelters, they also identified a number of psychological factors of potential interest. Several of the studies (e.g., Strope, et al. [92], Hale et al. [97]) specifically examined variables related to shelter manager leadership styles. Strope et al. [94] was the first to use family groups including adult males, adult females, and children as subjects, and several studies used measuring instruments to quantify certain psychological traits.

These exploratory shelter studies were followed by studies specifically intended to test certain hypotheses or address specific issues related to the psychological environment. Wright and Fenstermacher [98] used previouly developed instruments (by Wright and Hambacher [99]) with two shelter groups in an attempt to identify relationships between selected behavior characteristics and psychological factors under differing psychological support conditions. Meier and Engholm [100] investigated the human factors involved in using a packaged ventilation kit in a shelter. Smith and Meagley [101] attempted to determine the relationship between shelter expectations (perceptions of shelter conditions) and conditions actually encountered in a shelter. Newmiller, Francis, and Cooper [102] attempted to examine the relationships between defection (leaving the shelter prior to initial plans) and stress variables.

The latter study clearly pointed out a major shortcoming of using actual shelter experiences as a basis for studying the psychological environment. The study resulted in such a small proportion of defections (two effective defections from two groups of 51 each) that no relationships could be examined. A major weakness in most shelter-based research is that stresses resulting from psychological factors have not been subjected to detailed study because of inherent problems in creating a sufficiently stressful environment. Dependence upon voluntary shelter confinement under nonemergency conditions has only minimally presented the anticipated psychological environment.

To address the difficulty noted above, several shelter studies made deliberate attempts to generate a perception of environmental threat in subjects and to assess the effects of perceived threat on performance. A study of Smith, Collins, and Meagley [103] approached the limits of what could be considered ethical use of human subjects for research purposes in their attempt to create a threatening shelter environment. They utilized a shelter submerged in water and developed a test scenario that included apparent termination of the air supply to the shelter and some flooding of the shelter area. This exploratory study appeared to show a relationship between the perception of threat and management performance, particularly in the area of social behavior. A later study [104] utilized a habitat located in 50 feet of water off Freeport, Grand Bahama Island. The water surrounding the shelter was expected to provide an effective simulation of some of the threatening aspects of emergency shelter occupancy. No particular relationships were noted between the presence of stress and performance in the shelter. The researchers concluded that the static nature of the perceived threat resulted in too low a level of stress to impede performance for most individuals on most cognitive tasks.

In a further attempt to investigate psycho-social problems likely to arise during confinement in a shelter, a number of researchers conducted studies in nonshelter settings that were thought to be more representative of the anticipated shelter psychological environment. For example, a study by Wright and Hambacker (1965) to investigate relationships between certain behavior patterns and certain psychological stresses during confinement utilized carefully selected subjects in the admission wards of selected psychiatric hospitals. The use of mental hospital patients was expected to permit a study of individuals in a state of shock similar to that of people entering a shelter. In addition, bias problems with the use of volunteer subjects was thought to be minimized.

Other researchers considered other than shelter situations such as submarine habitability and polar isolation [105], wartime internment camps [106], and isolated radar bases [107]. In addition, reports of World War II bombshelter experiences have been studied [108]. Wallace [109] conducted a survey of the literature on human behavior in extreme situations and noted that the bulk of the publications on disaster are found in the popular press: magazines, newspapers, and trade books. He noted that journalistic and scholarly accounts constitute a vast reservoir of empirical information on hundreds of disasters from which scientists can draw data for their own studies.

Studies in settings and situations such as are summarized above have produced an abundance of information regarding psychological factors likely to be of importance in shelter occupancy in a crisis. Not only have critical factors been identified but also some knowledge has been gained of the likely behavioral outcomes of the factors both individually and in various combinations.

The major weakness of other than actual shelter studies such as those noted above generally is acknowledged to be that such studies, as with actual shelter studies, deal only superfically if at all with realistic depths of emotions likely to be present in shelter occupancy in a crisis. Fortunately, however, the general psychological literature does deal with such emotions. For example, while realistic levels of fear of physical danger rarely if ever were encountered and studied in shelter research, such levels of fear have been extensively studied in the broad field of psychological research. A review of this extensive literature is, of course, beyond the scope of this investigation. The purpose of these comments is to make clear that what is known about the behavioral impact of the shelter psychological environment is not limited exclusively to findings of studies such as those noted above. Rather, these studies provide a framework for drawing on the broad field of psychological research for more detailed cause and effect relationships.

2. Psychological Factors Identified as Being Important

Studies reported in the literature indicate two categories of psychological factors of interest in shelter occupancy planning. First are a number of primarily physiological factors (e.g., food deprivation, excess heat) that are known also to evoke psychological responses. The other factors (e.g., lack of privacy, fear of physical harm) are primarily psychological in nature. What appears to be the major factors of interest are listed in Table III-5. While this exact list was found nowhere in the literature, it is thought to represent a reasonable structuring of stated and implied factors identified and discussed in the literature of interest.

3. Likely Impacts of the Psychological Factors of Importance

Before discussing the nature of likely impacts of psychological factors on shelter occupancy, some perspective may be gained by considering the likely magnitude of the impacts. McCermott [110] noted that, while we must continue to probe the problems related to mass behavior in a disaster, considerable evidence has been gathered to refute the notion that violence, hysteria, and general mayhem would be rife. Wright et al. [98] stated that "it would seem then that we are not concerned with extreme behaviors, but rather with the vast scope of intermediary problems, the extent and severity of which are not known." Wright further noted that any aspects of confinement that contributes, either negatively or positively, to the optimum functioning of an individual should be identified, defined, and explored. Fritz [111] noted that if disaster studies have taught us nothing else, they have taught us that man is a highly adaptive social animal when he is directly confronted

TABLE III-5. REACTIONS TO STRESSFUL ENVIRONMENTAL STIMULI

Stressful Environmental Stimuli	Primary Reactions Characteristic of Sympathetic and/or Parasympathetic Nervous System	Primary Psychological and Psychophysiological Reactions
Oxygen deprivation	Irritability, anger, euphoria, depression, apathy, lethargy	Reduced intellectual functioning, inhibited memory, reduced ability to concentrate, increased tendency toward hallucinations
Excess CO_2	Irritability, euphoria, depression	Reduced ability to concentrate
Water Deprivation	Irritability, euphoria, depression	Reduced intellecutal functioning, inhibited memory, increased tendency toward hallucinations, increased confusion
Food deprivation	Irritability, depression, apathy, lethargy	Decreased coordination, reduced ability to concentrate, decreased interest, decreased ambition, decreased self-discipline
Excess heat	Irritability and depression	Reduced ability to concentrate, loss of attention
Excess humidity	(Not specifically listed by Hanifan et al. [112]. Presumably same as for heat.)	(Not specifically listed by Hanifan et al. [112]. Presumably same as for heat
Lack of comfortable standing/sitting/reclining facilities (Listed by Hanifan et al. [112] as crowding and confinement.)	Irritability, aggression, euphoria, depression, apathy	Decreased coordination, reduced intellectual functioning, reduced ability to concentrate, reduced vigilance
Noise	Irritability, aggression, depression	Reduced ability to concentrate, reduced vigilance, reduced attention
Inadequate lighting	(None noted by Hanifan et al. [112].)	Decreased coordination
Offensive odor	Anger	Lowered morale

with clear challenges to his continued existence. He has survived every conceivable form of danger and horror in the past and, short of total annihilation, he will continue to do so in the future.

As reflected above, the literature generally considers the psychological environment to be an important factor in shelter occupancy, but not necessarily the <u>most</u> important. If one must choose between, for example, reduced fear and reduced hunger, the latter likely is a more appropriate choice. The following discussion of the likely impacts of psychological factors on behavior, then, should be viewed from that perspective.

In their study of the physiological and psychological effects of overloading fallout shelters Hanifan, Blockley, Mitchell, and Strudwick [112] reviewed data from a number of sources in presenting some conclusions regarding the likely impact of various shelter-related factors. Their reports provide an excellent summary of a number of research findings and, at the same time, show the complexity of relating specific behaviors to specific physiological and psychological factors. Of particular interest here is their graphic presentation of information related to factors that are primarily physiological but that also have psychological impacts. A simplified presentation of pertinent data from their report was presented as Table III-5.

As one indication of the complexity of relating a specific reaction to a specific stessful stimuli, Hanifan et al. [112] noted that reactions to food deprivation, vitamin deficiency, heat and humidity, cold and wind, oxygen deprivation, foul odors, fatigure, sleep deprivation, noise, glaring or poor lighting, sensory deprivation, and confinement all generally included irritability. Thus, a detailed study of this particular reaction is complicated not only by the wide range of triggering stimuli but also by individual differences. Each individual will react differently depending upon his particular predisposition, how effectively he perceives the shelter as a means of survival, and his experiences immediately prior to entering the shelter.

Wright et al. [113], in their discussion of the shelter psychological environment, provided a summary of individual behavioral response patterns in disaster-induced stress. They noted that the environment created by disaster is much different than that of normal times in that it produces stress of a severity and quality not generally encountered. They then described three major behavioral patterns that evidence themselves in normal individuals undergoing stress in disasters: normal reactions, depression or withdrawal reactions, and hyperactive responses. Few individuals are able to (in a disaster environment) remain calm and under complete control. Most people show overt stress reactions. They may tremble, their knees shake, tears may appear, they may weep openly, perspire excessively, feel weak in the knees or stomach, become nauseated and hot, speech may be disconnected, thoughts unorganized, and so forth. Each person will respond differently. But all are <u>normal reactions</u> to danger. They are temporary. They serve to alert us to action. They are our body's signals that something is or may be wrong, and they are the body's way to prepare for unaccustomed action. Fortunately, most people regain composure shortly and adapt to the situation as required, and these "signals" terminate.

People who appear to be completely unaware or detached from a dangerous situation are experiencing a depressed or withdrawal reaction. They seem puzzled or preoccupied with the disaster. They may gaze vacantly into space, may not respond when spoken to, or may stand or sit quietly in the midst of the danger. These people cannot respond and are unable to help themselves or others. Their first step toward regaining their normal behavior, once contact with reality is reestablished, will be to become busy with some quiet activity that can be done by rote, i.e., without thinking. Others will have to assist them in initiating their recovery. The rote or mechanical activity can spread to simple tasks carried out under direction and supervision, followed later by assuming responsibilities when the person is ready. These are normal people using abnormal behavior responses temporarily under the circumstances of stress.

Some individuals resort to overactive responses. They become excited, talk rapidly, joke, make endless suggestions and demands. They appear capable and confident and may seem to be leadership material. However, their behavior is purposeless and disorganized. They jump from task to task at the slightest distraction and create confusion for others. These individuals frequently interfere with the effectiveness of establishing leadership. Normal composure can be achieved for them through guided activity. Since they have a need to be active, their energies should be directed toward tasks requiring physical activity. As they return to normal, they can be given greater responsibilities. Working creates opportunities that contribute to the well being of others and to their own self-confidence.

Wright et al. [99] reviewed a number of pertinent studies and concluded that psychological adjustment in a shelter falls short when one or more of the following conditions are psychologically predominant:

- Generalized fear of the unknown. The reduction of a threat to personal safety is a frequent goal of individuals in an emergency or on an assignment involving a high degree of danger. Attainment of this goal is frustrated when unknown or exaggerated fears persist regarding the nature of the hazards one is facing. The result of this frustration is made evident though a lowering of morale and passive, regressive behavior, or hyperactive random behavior bordering on panic.
- Lack of situational structure. Goal attainment is persistently thwarted when the goals and paths leading to them are undefined. Again, the general results are a reduction of morale and overly

passive or inconsistent, random behavior. Individuals finding themselves in threatening situations will attempt to induce structure in both the physical and psychological fields. This may comprise a goal in itself (desire to reduce anxiety or fear of the unknown), or it may be a preliminary step toward a defined goal (for example, escape from a threatening situation). In either case, the goal is unobtainable if the individual either lacks the information necessary to obtain the desired level of structure or for some reason is unwilling to accept the information that is available.

- Resentment of confinement. Physical confinement will serve to thwart any goal attainment when the goal lies outside the bounds of the confinement. The result of this frustration may take the form of apathy or hostile aggressions, and, if present, will usually be directed toward whatever the individual considers to be the confining agency. Psychological confinement will produce the same reactions, but is more subtle in nature. Severe psychological confinement will interfere with familiar, structure-maintaining behavior patterns.

- Loss of identity. Situations posing a severe threat to the personal safety and survival of the individual often negate previously established mechanisms of personal identity. Individuals who resent this status-leveling effect may become frustrated when attempts to regain their prior status are to no avail. Failing to regain status recognition, they may revert to regressive behavior characterized by withdrawal, overt hostility, and increased possessiveness.

The above indicates that the likely impact of adverse psychological factors in shelter occupancy can, at a minimum, inhibit adjustment and productivity during and following occupancy and, at worst, be life threatening to both the individual and the group. Since the general nature of the psychological factors and the likely responses to those factors are known, what remains is to use this knowledge to (1) modify the shelter environment to minimize the potential stress and (2) accept that some stress is inevitable and develop shelter occupancy plans to accommodate responses to that stress. The following subsection summarizes recommendations for such shelter occupancy planning suggested by the literature.

4. <u>Recommendations for Minimizing the Negative Impact of Responses to the Psychological Environment</u>

Recommendations for minimizing the negative impact of responses to the psychological environment in shelter occupancy, as noted in the literature, may be summarized under the following headings.

- Shelter manager selection and training
- Public education
- Shelter facility/activity planning.

Following is a brief discusison of each of these types of activities.

a. <u>Shelter Manager Selection and Training</u>

While the importance of selecting appropriate individuals for shelter managers often is noted in the shelter occupancy literature, quite limited guidance is provided regarding selection critiera or selection processes. Smith et al. [103,104], for example, provided limited recommendations regarding selection criteria and suggested the use of a pair of standardized instruments for determining stress tolerance in prospective shelter managers. However, the researchers clearly pointed out the severe limitations on their findings. More specific indications of selection criteria would appear to be available from the general field of psychology. For example, reports on the United States Antarctic Research Program [114] noted screening criteria for personnel selected to "winter over" at the South Pole Station. Since the prolonged isolation in the station presents a psychological environment somewhat similar to that expected in shelter occupancy, the screening criteria also would be reasonably appropriate for shelter managers.

A number of studies [112,115,16] recommend shelter manager training as a means of affecting the shelter psychological environment. Suggestions for training include providing an understanding of the nature of the environmental stresses and reactions to them; possible ways of minimizing stress in particular shelters; techniques of group leadership including setting up channels of communication, delegating responsibility, and running democratic group discussions; and ways of maintaining a well-defined, meaningful, and organized program of activities.

b. Public Education

Shelter occupancy studies that make suggestions for improving the shelter psychological environment [117,118,101] recommend an intensive training, indoctrination, and familiarization program for the general public to inform it of the realities and obligations of shelter life. A study conducted by Smith and Meagley [101] appears to confirm the need for providing the general public with a realistic idea of most likely shelter conditions. The major purpose of their study was to experimentally determine the relationship between shelter expectations and behavior during subsequent shelter occupancy. The study concluded that individuals whose expectations were confirmed by actual shelter conditions participated more actively in critical shelter activities and more readily accepted the actual conditions than did individuals who had less realistic expectations. This was true whether the less realistic expectations were of more basic conditions or of more supplemental conditions. Comments by Kennedy [119] appear to support the idea of realism in public education. He noted that "if [the general public] sees sheltering as a period during which they are stretched out corpse-like, obviously they are not going to like it, nor are they going to take much stock in the possibility that they will have to do this. Conversely, if you tell them that sheltering is going to be an esthetic experience, they are not going to believe you."

Several studies [117,118] indicated that public education should address post-shelter conditions as well as within-shelter environment. Chenault et al., in addressing this issue, stated that "one of the major psychological factors with which survivors are likely to have to contend is insecurity in the face of an unknown future and fear that the future will bring a worse fate than they have already experienced. They are likely to be confused, anxious, and fearful of changes that might be associated wtih loss of their job, loss of wealth, and disappearance of their social or political position. To counteract the debilitating influence of this factor, survivors need a realistic definition of their situation and of the changes they can expect in their former comparatively stable situation. They will need to be made to feel that their efforts are necessary to a concerted recovery effort and that their situation will ultimately improve if they expend those efforts. The realization needs to be created in survivors that they have a real and personal stake in the national recovery effort. In short, even in the undamaged areas, the whole social structure within which people live and from which they derive meaning for their lives and identity for themselves will be perceived as having changed and will no longer appear as a stable reality providing meaningful rules and guides for behavior. One of the important functions of post-attack socioeconomic policies will be to aid in re-establishing a stable social reality for the survivors in terms of which the behavior asked of them can be understood as meaningful" [117].

c. Shelter Facility/Activity Planning

While shelter planning must accommodate a number of factors in addition to the anticipated psychological environment, a number of studies make recommendations that primarily address psychological needs. Following is a brief discussion of such recommendations for shelter facility planning and shelter activity planning.

Fritz [111] reflected the concerns of a number of researchers in stating that the building of individual family shelters should be discouraged and emphasis placed on neighborhood, communal, and large-group shelters. He noted the following reasons for such an emphasis:

- Widespread feelings of isolation, abandonment, and consequent demoralization are much more likely to develop when there are millions of small, scattered shelter units.
- People obtain stronger feelings of security and support in large groups.
- The larger the group, the greater the spread of skills needed for shelter management and survival in the post-attack environment; hence the less the need for special training of shelter personnel.
- The smaller the number of shelters, the easier the task of communication between and among shelters and the greater the possibility of achieving order in the post-shelter attack on emergency relief and rehabilitation problems.
- The very act of planning, building, and equipping neighborhood and community shelters emphasizes the need for mutually cooperative behavior and combats the tendency for individuation of behavior--a tendency that poses the greatest control and administrative problems in a post-disaster period.

Fritz further noted that every effort should be made to avoid the pure "mass shelter," i.e., the adventitious and fortuitous grouping of anonymous individuals. He stated that even in highly mobile areas of large cities, it is not necessary to think solely in terms of the mass shelter concept. Large department stores, business and professional offices, public transportation and maintenance crews, and many other existing groups can be used to provide the essential nuclei of shelter occupancy and organization. There will always be a certain proportion of the population that will be adventitious shelter occupants, of course, but these people can be integrated around a relatively stable core of people whose presence and preexisting organization can be predicted with considerable certainty. Whenever possible, shelters should be located and built to encapsulate combinations of existing social groups whose membership and skills supplement and complement each other, e.g., groups having physical prowess or technical knowledge and those having social skills; groups with dependent membership and those with active, able-bodied, and productive functions. The aim in each case would be to replicate as closely as possible a total, self-sufficient community.

Fritz maintained that every effort should be made to incorporate multiple peacetime uses into shelter construction, so that the shelter is not viewed simply as a place of refuge in the event of attack but as a place that has value to current life. The association of the structure with reward and the familiarity with its design that comes through continued use also served to eliminate the strangeness and potential fear-provoking element of shelter life.

Some studies [116,120] suggested specific permanent partitioning and physical arrangements of shelters as a means of addressing certain psychological and psychosocial needs. Fritz, on the other hand, suggested that flexibility of physical design should be the keynote of all shelter construction, and that highly rigid, predetermined, and unchangeable design patterns should be avoided at all costs [111].

Fritz noted that shelter occupants should literally be able to remake and restructure their shelter environment in accordance with the different needs and characteristics of the shelter occupants and in relation to the different needs occurring at different time periods of occupancy. He stated that the need for flexibility becomes obvious when we think of the shelter as serving multiple functions both in peacetime and in wartime (not only as a place of refuge for, say, 2 weeks but also as a habitat that may have to be occupied for months or years following an attack) and when we add the likelihood of unforeseen needs resulting from the particular characteristics of the shelter occupants or from special circumstances. Moreover, the ability to carve out, change, and restructure their environment gives people an opportunity to engage in socially meaningful tasks and provides a sense of satisfaction that goes far beyond the simple use of space for survival purposes.

A reliable means of communications between shelters was highly recommended by a number of studies [105,114,115,120]. Fritz [111] succinctly clarified such a recommendation by stating that all shelters should be tied together with an invulnerable system of two-way communication, so that every shelter can both send and receive messages. The use of this network should give cognizance to the social-psychological needs for information among the shelter occupants as well as the operational needs required for in-shelter and post-shelter survival. Fritz further noted the following general information needs of shelter occupants:

- They will want to know what has happened to the Nation as a whole, to their communities, and to their homes
- They will want to know how the national leadership feels about the war situation and what the leaders expect of them
- They will want and need information on the whereabouts and condition of missing loved ones
- They will be concerned with how long they will have to remain in the shelter, and whether or not outside aid will be available to solve emergency problems of shelter life
- They will want and need orientation about the future: what life will be like when they emerge, what the future prospects for themselves and their children and other loved ones will be.

Suggestions for provisioning the shelter to address psychological needs included consideration of the use of drugs such as sedatives and tranquilizers [112], the extensive use of training aids and simplified instruction manuals for operating equipment [110], and provision of complete shelter manager guides for use in those situations where a well-trained manager is not available [115,116].

A final family of suggestions were related to activity planning. Several studies [106,107] suggested planned recreational activities. Other studies [111,112,115] recommended planned work-related activities. Rohrer, for example, noted that meaningful activity could consist of providing "do-it-yourself kits" made up of raw materials and letting shelter occupants build the living arrangement that they want in the shelter. This would provide them, for example, with permissible individualistic ways of creating conditions of felt privacy and objects that they might need, such as benches and tables; but more importantly, it would provide activity that would serve greatly to reduce the anxiety that they felt under conditions of shelter living.

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IV. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

In preparing this state-of-the art assessment of shelter habitability research, RTI reviewed and summarized numerous documents relating to predicting, controlling, and monitoring the thermal, chemical, and biological environments in fallout shelters and to occupant responses to a range of shelter environmental conditions. This section contains general conclusions of the research related to shelter habitability and presents recommendations for further research on the subject. The conclusions identify areas where there is general agreement among researchers, while the recommendations identify areas where there is disagreement among researchers or where there are still unanswered questions.

Neither the conclusions nor the recommendations are intended to cover all aspects of shelter habitability but only include major areas of interest. Future research needs in shelter habitability will depend heavily on future directions of civil defense programs and policies.

A. Conclusions

A great deal of research activity has been devoted to investigations of natural ventilation characteristics of shelters. There is general agreement among researchers that above-ground shelters will have adequate ventilation from natural sources, which include both wind and thermal buoyancy. There is also general agreement that below-ground shelters will not have adequate natural ventilation to permit occupancy at the rate of one person per 10 square feet of floor area. These shelters will need either forced ventilation or some other means of mechanical heat removal. In research studies related to forced ventilation, there is general agreement that PVKs and KPKs are well suited for supplying and distributing adequate ventilation in shelters if the devices are available.

In research studies related to the chemical shelter environment, there is general agreeement that maintaining an adequate supply of oxygen and preventing excess CO_2 is not a difficult problem in shelters that can be left open to the atmosphere. However, there is also general agreement that if fires are burning near a shelter, combustion products may enter the shelter and present severe problems for the shelter occupants. In such a case, there may be a need to close the shelter for a period of time. If a closed shelter period is required, some means other than ventilation would be needed to supply oxygen and remove CO_2.

Considerable research has addressed the physiological and psychological responses of humans to environmental stresses. Thermal, chemical, and biological stresses are quite well understood. Responses to individual stresses can be predicted based on information gathered in occupational, military, and basic research. Sources of such information include human and animal toxicology, human physiology, epidemiology, and analysis of natural and man-made disasters (floods, fires, and extreme crowding). Two areas of research related to shelter habitability that have not been adequately studied are the response of humans to multiple stresses and the response of sensitive persons to environmental stresses.

Thermal stress is expected to be minimal in the shelter standard range, 50°F-82°F ET. Drinking water supplies greater than 1.75 liters per day per person will be adequate for most of the population at standard conditions. Persons identified as heat sensitive include those over 65 years of age or under 1 year of age, physically unfit, obese, cardiovascular diseased, diabetic, kidney impaired, gastrointestinal diseased, respiratory diseased, rashed, and persons undergoing strenuous exercise. Above an ET of 82° F there will be more severe physiological strain and fluid replacement is critical. Cold stress is not expected to be a problem even if temperatures fall below 50° F unless clothing or other insulating materials are not available.

Few investigations have been concerned with the multiple stresses of combustion--heat, anoxia, CO_2, CO, and noxious gases. One can predict the levels for CO_2, CO, O_2, NO_x's, or smoke at which adverse reactions occur for both sensitive and normal populations; however the physiological and toxicological responses to multiple combustion products are extremely difficult to study in humans. Despite this, man's experience with modern urban fires attest to the life threatening potential of exposure to combustion products.

Communicable diseases will be brought into shelters and they will spread. It is expected that nearly all shelter occupants would contract colds or other minor respiratory infections. Gastrointestinal disorders could become a problem as sanitary conditions decline. Communicable diseases such as hepatitis, typhoid, and amebiasis may be initiated and become a problem during the post-shelter period. Resistance to many communicable diseases is related to state of health and the body's immune response system. Environmental stresses, especially radiation, greatly affect the severity of communicable diseases and would be expected to do so in sheltered populations.

Additional physical shelter features, such as lighting and noise, are expected to involve little health risk. Psychological responses to environmental and post-shelter stresses would be a major habitability element. Though psychological factors of shelter life cannot be easily duplicated for study, the expected psychological response of sheltered individuals would not necessarily be one of extreme violence, hysteria, or complete withdrawal.

Normal reactions would include depression-withdrawal and overactivity and would be temporary. Destructive psychological reactions can be minimized by the actions taken by sheltered populations and civil defense personnel, e.g., such as shelter manager selection, public education, shelter facility and shelter activity planning.

B. Recommendations

There are a number of research areas related to shelter habitability where researchers disagree and where there are unanswered questions. One such area, which is critical to the success of a shelter program, is the 90 percent adequacy criterion for shelter ventilation. Recommended shelter ventilation rates are based on maintaining an average ET of 82° F for 90 percent of the days of the year. While this may seem adequate for most situations, research has indicated that the time when the recommended ventilation is not adequate tends to occur as a few lengthy periods rather than a large number of short periods. These implications cast serious doubt on the validity of the 90 percent adequacy criterion. For shelters located in urban areas, the problem is compounded by urban heat buildup. Research results indicate that urban temperatures, especially nighttime temperatures, are significantly higher than weather station temperatures. This phenomenon could dramatically affect shelter temperatures but was apparently not a consideration when ventilation recommendations were developed. RTI recommends that both the 90 percent adequacy criterion and the urban heat buildup be reevaluated with regard to their impact on shelter ventilation rates.

A number of shelter habitability questions remain that are difficult to research. These include (1) the response of sensitive individuals to environmental stresses, (2) the human response to multiple stresses, and (3) the character of combustion products. There are also real questions regarding medical, water, sanitary-hygiene, and food in a shelter situation.

The chemical environment of urban post-attack shelters has not been adequately investigated. The expected fires found in urban areas would produce large amounts of toxic and noxious compounds. It is recommended that models be developed to predict, over the shelter period, the combustion products and their concentrations that would be expected in urban atmospheres. Though each urban area is somewhat different in building materials and configuration, a rough profile of combustibles could be valuable in predicting the chemical nature of air that would be brought into open shelters. If a model is developed from which an atmospheric profile can be drawn, then it follows that open shelter atmospheres can be predicted. Where contaminant concentrations reach toxic levels, a closed shelter period would be recommended. It would be useful to reexamine whether closed shelters would be needed in order to maintain habitability.

Heat stress indexes continue to be investigated in terms of their ability to predict physiological stress. In the light of recent reviews of heat stress indexes, such as that done at the University of Cincinnati and at a NIOSH-sponsored symposium, a shelter heat stress index more appropriate than the Effective Temperature Scale might be recommended. Though research on heat stress centers on work in hot environments, it would be of interest to shelter planners to know what literature could be extrapolated to the shelter experience.

Sensitive individuals have been identified, to the extent possible, in this report. Many persons who are institutionalized for example, would be sensitive to one or more of the potential environmental stresses. Shelter standards and supplies may not be sufficient to maintain special populations and, therefore, it would be important to develop strategies for attending to their needs.

Two important features of the psychological response of shelter occupants are identified in this report. They are: (1) psychological reactions may be severe though temporary, and (2) actions could be taken to reduce or manage psychological stress. Information and training materials should be developed for in-shelter use and for shelter planning. Locating shelters in known public areas and the dissemination of accurate descriptions of shelter life are but two examples of strategies that could be taken to reduce psychological stress. Material could be developed as part of shelter manuals.

Medicines are an integral part of the state of health of many individuals and would continue to be under shelter conditions. No thorough investigation has been undertaken to define the medicine requirements of the U.S. population under a crisis on the scale of a nuclear attack. It is important to address both the requirements of the sheltered population and to study the availability of medicines. Strategies for meeting these needs could then be developed.

As part of the medical care strategy for a sheltered population, it is recommended that health manuals be available, such as Medical Care in Shelters (OCD-1963), a psychological stress manual, and a guide to communicable disease, sanitation and hygiene, and radiation-induced problems. A review of presently available health guidance materials would allow shelter health and medical planning to be done using the most appropriate sources of information.

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Wright, M. D., R. Chessin, M. Laney, and L. Cox
September 1982 (UNCLASSIFIED) 192 pages

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The objectives of this study were to assess the state-of-the-art of shelter habitability research, to describe nuclear weapons effects and mitigation techniques, to summarize current civil defense programs and policies, and to identify future research needs related to shelter habitability. The work consisted of an extensive review of civil defense literature, a review of non-civil defense literature through computer searches, and personal communications with individual researchers.

The information obtained was summarized into a state-of-the art assessment of research related to shelter habitability. General conclusions were listed to identify areas where there is general agreement among researchers. Recommendations for further study were made for areas where there is disagreement among researches and where there are important unanswered questions.